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# Effect of vermiculite, quarry dust and steel slag in self cured fly ash bricks

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**Abstract**
A brick is a building material used to make walls, pavements and other elements in masonry construction. Pulverized ash brick or Fly ash brick technology is a process of converting industrial waste materials into quality building materials. At present, the technology is well established in converting thermal power plant waste into quality bricks. The advantages of using fly ash brick are, the brick carries good compressive strength, provide better thermal insulation than red clay bricks, cheaper compared to clay bricks and are environment friendly. One of the important ingredients of fly ash brick is natural sand or river sand. However, due to the increased use of bricks in almost all types of construction works, the demand of natural or river sand has been increased. The infrastructure development such as express highway projects, power projects and industrial developments have started in a big way now. Available natural sand is getting depleted and also it is becoming costly. Thus, to meet these increased demands of construction industry, excessive quarrying of sand from river beds is taking place causing the shortage of natural sand. This scarcity of natural sand due to such heavy demands in growing construction activities have forced engineers to find a suitable substitute. In this study an attempt has been made to identify the strength of fly ash bricks in which the natural sand is replaced with vermiculite, quarry dust and steel slag in the proportions of 10%, 25%, 50%, 75% and 100%. The best proportion of GGBFS in the fly ash bricks is also identified in this report. In this report the fly ash bricks are self cured by forming geo polymers.

**Keywords:** Fly ash bricks, GGBFS, vermiculite, quarry dust, steel slag, geo polymers

## 1. Introduction
### 1.1 Fly ash bricks
#### 1.1.1 General
Pulverized fuel ash (PFA) commonly known as fly ash is a useful by-product from thermal power stations using pulverized coal as fuel and has considerable pozzolanic activity. This national resource has been gainfully utilized for manufacture of pulverized fuel ash-lime bricks as a supplement to common burnt clay buildings bricks leading to conservation of natural resources and improvement in environment quality.

Pulverized fuel ash-lime bricks are obtained from materials consisting of pulverized fuel ash in major quantity, lime and an accelerator acting as a catalyst. Pulverized fuel ash-lime bricks are generally manufactured by intergrading blending various raw materials are then moulded into bricks and subjected to curing cycles at different temperatures and pressures. On occasion as and when required, crushed bottom fuel ash or sand is also used in the composition of the raw material. Crushed bottom fuel ash or sand is also used in the composition as a coarser material to control water absorption in the final product. Pulverized fuel ash reacts with lime in presence of moisture from a calcium hydrate which is a binder material. Thus pulverized fuel ash – lime in presence of moisture forms calcium – silicate hydrate which is binder material. Thus pulverized fuel ash – lime brick is a chemically bonded bricks.

These bricks are suitable for use in masonry construction just like common burnt clay bricks. Production of pulverized fuel ash-lime bricks has already started in the country and it is expected that this standard would encourage production and use on mass scale. This stand lays down the essential requirements of pulverized fuel ash bricks so as to achieve uniformity in the manufacture of such bricks.

### 1.1.2 Market Demand

180 billion tons of common burnt clay bricks are consumed annually approximately 340 billion tons of clay- about 5000 acres of top layer of soil dug out for bricks manufacture. Soil erosion, emission from coal burning or fire woods which causes deforestation are the serious problems posed by brick industry. The above problems can be reduced to some extent by using fly ash bricks in dwelling units.

Demand for dwelling units likely to raise to 80 million units by year 2015 for lower middle and low income groups, involving an estimated investment 0f $670 billion, according to the associated chamber of commerce and industry. Demand for dwelling units will further grow to 90 million by 2020, which would requires a minimum investment of $890billion. The Indian housing sector at present faces a shortage of 20million dwelling units for its lower middle and low income groups which will witness a spurt of about 22.5million dwelling units by the end of Tenth plan period. There is ample scope for fly ash brick and block units.

### 1.2 GGBFS as eco friendly

Both GGBFS (Ground Granulated Blast Furnace Slag) and PFA (Pulverized Fuel Ash) are by-products of industry and the use of them is environmentally friendly. Most importantly, with GGBFS and PFA adopted as partial replacement of cement, the demand for cement will be drastically reduced. As the manufacture of one tonne of cement generates about 1 tonne of carbon dioxide, the environment could be conserved by using less cement through partial replacement of PFA and GGBFS.

On the other hand, the use of GGBFS and PFA as partial replacement of cement enhances the long-term durability of concrete in terms of resistance to chloride attack, sulphate attack and alkali-silica reaction.

### 1.3 Need for the replacement of sand in bricks

A brick is building material used to make walls, pavements and other elements in masonry construction. In India, the conventional brick is mostly produced by using natural sand obtained from the riverbeds as fine aggregate. The advantage of natural sand is that the particles are cubical or rounded with smooth surface texture. The grading of natural sand is always not ideal. It depends upon place to place. Being cubical, rounded and smooth textured, it gives good workability. One of the important ingredients of conventional brick is natural sand or river sand. However, due to the increased use of bricks in almost all types of construction works, the demand of natural or river sand has been increased. The infrastructure development such as express highway projects, power projects and industrial developments have started in a big way now. Available natural sand is getting depleted and also it is becoming costly. Thus, to meet these increased demands of construction industry, excessive quarrying of sand from river beds is taking place causing the shortage of natural sand. This scarcity of natural sand due to such heavy demands in growing construction activities have forced engineers to find a suitable substitute. In this project vermiculite, quarry dust and steel slag were utilized for the replacement of natural sand.

## 2. Characterization of materials

### 2.1 Materials used

The materials used in this research work are explained below.

**Binder**

- Fly ash
- GGBFS (Ground Granulated Blast Furnace Slag)

**Aggregate**

- River Sand
- Vermiculite
- Quarry Dust
- Steel slag

**Liquid for curing**

- Alkaline solution

### 2.2 Binder

### 2.2.1 Fly ash

Fly ash, also known as flue-ash, is one of the residues generated in combustion, and comprises the fine particles that rise with the flue gases. Ash that does not rise is called bottom ash. In an industrial context, fly ash usually refers to ash produced during combustion of coal. Fly ash is generally captured by electrostatic precipitators or other particle filtration equipment before the flue gases reach the chimneys of coal-fired power plants, and together with bottom ash removed from the bottom of the furnace is in this case jointly known as coal ash. Depending upon the source and makeup of the coal being burned, the components of fly ash vary considerably, but all fly ash includes substantial amounts of silicon dioxide ($SiO_2$) (both amorphous and crystalline) and calcium dioxide (CaO), both being endemic ingredients in many coal-bearing rock strata.

### 2.2.1.1 Class F fly ash

The burning of harder, older anthracite and bituminous coal typically produces Class F fly ash. This fly ash is pozzolanic in nature and contains less than 20% lime (CaO). Possessing pozzolanic properties, the glassy silica and alumina of Class F fly ash requires a cementing agent, such as Portland cement, quicklime, or hydrated lime—mixed with water to react and produce cementitious compounds. Alternatively, adding a chemical activator such as sodium silicate (water glass) to a Class F ash can form a geopolymer.

**Fig 2.1:** Fly ash at site

Fly ash used in this experiment work is brought from Sri Damodaram sanjeevaiah thermal power station, Nellatur. The physical and chemical properties of fly ash used in this work are given in Tables 2.1 and 2.2 respectively.

**Table 2.1:** Physical properties of flyash

| Parameters | Fly Ash |
|---|---|
| Bulk Density (gm/cc) | 0.9-1.3 |
| Specific Gravity | 1.6-2.6 |
| Plasticity | Lower or non-plastic |
| Shrinkage Limit (Vol stability) | Higher |
| Grain size | Major fine sand / silt and small per cent of clay size particles |
| Clay (per cen) | Negligible |
| Free Swell Index | Very low |
| Classification (Texture) | Sandy silt to silty loam |
| Water Holding Capacity (WHC) (per cent) | 40-60 |
| Porosity (per cent) | 30-65 |
| Surface Area (m2 / kg) | 500-5000 |
| Lime reactivity (MPa) | 1-8 |

**Table 2.2:** Chemical composition of fly ash

| Compounds (%) | Fly Ash |
|---|---|
| SiO2 | 38-63 |
| Al2 O3 | 27-44 |
| TiO2 | 0.4-1.8 |
| Fe2 O3 | 3.3-6.4 |
| MnO | b.d-0.5 |
| MgO | 0.01-0.5 |
| CaO | 0.2-8 |
| K2 O | 0.04-0.9 |
| Na2 O | 0.07-0.43 |
| LOI | 0.2-5.0 |
| pH | 6-8 |

bd: below detection limit, LOI: Loss on Ignition

### 2.2.2 GGBFS (Ground Granulated Blast Furnace Slag)

Ground-granulated blast-furnace slag (GGBFS or GGBFS) is obtained by quenching molten iron slag (a by-product of iron and steel-making) from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder. The chemical composition of a slag varies considerably depending on the composition of the raw materials in the iron production process.

**Fig 2.2:** Sample of GGBFS

GGBFS used in this experiment work is brought from JSW industries ltd. Mumbai. The typical compositions of different chemicals present in GGBFS used in this work are given in Table 2.3

**Table 2.3:** Typical composition of different chemicals present in GGBFS

| S. No | Characteristics | Percentage |
|---|---|---|
| 1. | Fineness (m²/Kg) | 412 |
| 2. | Particle Size (Cumulative %) | 94.25/100 |
| 3. | Insoluble Residue | 0.23 |
| 4. | Magnesia Content | 8.73 |
| 5. | Sulphide Sulphur | 0.54 |
| 6. | Sulphide Content | 0.29 |
| 7. | Loss On Ignition | 0.17 |
| 8. | Manganese Content | 0.06 |
| 9. | Chloride Content | 0.010 |
| 10. | Glass Content | 90 |
| 11. | Moisture Content | 0.14 |

## 2.3 Aggregate

### 2.3.1 River Sand

A brick with better quality can be made with sand consisting of rounded grains rather than angular grains. River or pit sand must be used and not sea sand as it contains salt and other impurities. Sand is a naturally occurring granular material composed of finely divided rock and mineral particles. The composition of sand is highly variable, depending on the local rock sources and conditions, but the most common constituent of sand in inland continental settings and non-tropical coastal settings is silica (silicon dioxide, or $SiO_2$), usually in the form of quartz.

**Fig 2.3:** Sample of river sand

#### 2.3.1.1 Sieve Analysis of sand

The Sieve Analysis of sand is carried out to know the zone of the sand, the fineness of sand which gives good compaction of mix. The result of sieve analysis is given in Table 2.4.

**Table 2.4:** Sieve analysis of sand

| Sieve size | Weight Retained in GM | % passing |
|---|---|---|
| 4.75 mm | 20 gm | 97.8 |
| 2.36 mm | 13gm | 96.4 |
| 1.18 mm | 74 gm | 91.2 |
| 600 micron | 391 gm | 50.7 |
| 300 micron | 416 gm | 8.9 |
| 150 micron | 86gm | 1.6 |
| Total | 1000 gm | - |

From the sieve analysis the river sand undergoes Zone-II.

#### 2.3.1.2 Physical properties of sand

Before going to the experimental work we have to find the physical properties of sand like specific gravity and water absorption. The physical properties of sand are given below in Table 2.5.

**Table 2.5:** Physical properties of sand

| S. No | Description | River sand |
|---|---|---|
| 1. | Specific gravity | 2.71 |
| 2. | Bulk Density (Dry) (Kg/m$^3$) | 1480 |
| 3. | Bulk Density (Wet) (Kg/m$^3$) | 1695 |
| 4. | Water absorption (%) | 0.7 |

### 2.3.2 Vermiculite

Vermiculite is a mica-type mineral usually formed by hydrothermal alteration, such as biotite and phologopite (Addisson, 1995). Vermiculite has been used in various industries for over 80 years. It is used in the construction, agricultural, horticultural and industrial markets. Vermiculite is the mineralogical name given to hydrated laminar magnesium-aluminium-iron silicate which resembles mica in appearance. Vermiculite is a naturally occurring, inert laminar mineral that finds use in many constructions, industrial, home, agricultural& garden products composed of shiny flakes, resembling mica. When heated to a high temperature, flakes of vermiculite expand as much as 8-30 times their original size and forms like an ultra-light weight aggregate. The expanded vermiculite is a light-weight, non-combustible, highly absorbent, compressible, non-reactive, fire-resistant, and odorless material and has been used in numerous products, including insulation for attics and walls.

**Fig 2.4:** Sample of vermiculite

The chemical composition of vermiculite are given in Table 2.6

**Table 2.6**: Chemical composition of vermiculite

| Element | Weight percentage |
|---|---|
| SiO2 | 38-46 |
| Al2O3 | 10-16 |
| MgO | 16-35 |
| CaO | 1-5 |
| K2O | 1-6 |
| Fe2O3 | 6-13 |
| TiO2 | 1-3 |
| H2O | 8-16 |
| Other | 0.2-1.2 |

### 2.3.3 Quarry dust

Quarry dust, a byproduct of stone crusher industry was procured from a local quarry. As fine aggregate, quarry dust provides volume to the mix. It imparts workability, homogeneity and uniformity to the brick mix. The particle size distribution (sieve analysis) reveals that quarry dust corresponds to grading zone I as per IS 383:1970**.** Table 3.7 presents the physical properties of quarry dust .Higher fineness modulus indicates that the quarry dust is slightly coarser.

Quarry dust is characterized mostly by angular particles in contrast to rounded/spherical particles of natural sand.

#### 2.3.3.1 Sieve Analysis of Quarry Dust:

The Sieve Analysis of quarry dust is carried out to know the zone and the fineness of quarry dust. The result of sieve analysis is given in Table 2.7.

**Table 2.7:** Sieve Analysis of Quarry Dust

| IS sieve size(mm) | percentage finer |
|---|---|
| 4.75 | 89.202 |
| 2.36 | 59.625 |
| 2 | 50.705 |
| 1.18 | 33.804 |
| 1 | 30.049 |
| 0.6 | 20.19 |
| 0.425 | 14.557 |
| 0.3 | 8.924 |
| 0.15 | 0.943 |
| 0.075 | 0.2 |

From the sieve analysis, quarry dust undergoes Zone-I.

**2.3.3.2 Physical properties of quarry dust:** Before going to the experimental work we have to find the physical properties of quarry dust. The physical properties of quarry dust are given below in Table 2.8.

**Table 2.8:** Physical Properties of Quarry Dust

| Sl. No | Description | Quarry Dust |
|---|---|---|
| 1. | Specific gravity | 2.85 |
| 2. | Bulk Density (dry) (Kg/m$^3$) (Kg/m$^3$)VdjshfJDSJfjJdsfjNJGDENJHFHUHDSDDEDEDEDensity (Loose) kg/m3 | 1644 |
| 3. | Bulk Density (wet) (Kg/m$^3$) (Kg/m$^3$)ddfvjsdkjkdsjjgkdfjgijfisjgjsdjgijDeDeDensity(Compacted)kg/m3 | 1756 |
| 4. | Water absorption (%) | 0.6 |
| 5. | Fineness Modulus | 3.15 |

**Fig 2.5:** Sample of quarry dust at site

### 2.3.4 Steel Slag
### 2.3.4.1 Physical Properties
Steel slag aggregates are highly angular in shape and have rough surface texture. They have high bulk specific gravity and moderate water absorption (less than 3 percent). Table 2.9 lists some typical physical properties of steel slag.

**Table 2.9:** Typical physical properties of steel slag.

| Property | Value |
| --- | --- |
| Specific Gravity > | 3.2 - 3.6 |
| Unit Weight, $kg/m^3$ ($lb/ft^3$) | 1600 –1920(100 - 120) |
| Water Absorption | up to 3% |

### 2.3.4.2 Chemical Properties
The chemical composition of slag is usually expressed in terms of simple oxides calculated from elemental analysis determined by x-ray fluorescence. Table 2.10 lists the range of compounds present in steel slag from a typical base oxygen furnace. Virtually all steel slags fall within these chemical ranges but not all steel slags are suitable as aggregates. Of more importance is the mineralogical form of the slag, which is highly dependent on the rate of slag cooling in the steel-making process.

**Table 2.10:** Typical steel slag chemical composition

| Constituent | Composition (%) |
| --- | --- |
| CaO | 40 – 52 |
| $SiO_2$ | 10 – 19 |
| FeO | 10 – 40 (70 - 80% FeO, 20 - 30% Fe2O3) |
| MnO | 5 – 8 |
| MgO | 5 – 10 |
| $Al_2O_3$ | 1 – 3 |
| $P_2O_5$ | 0.5 – 1 |
| S | < 0.1 |
| Metallic Fe | 0.5 – 10 |

**Fig 2.6:** Steel slag at site

## 2.4 Alkaline Solution
The Alkaline solution used for experimental investigation is obtained from the combination of
Sodium silicate solution and Sodium Hydroxide in the form of pellets. It is observed that the Geopolymers with Sodium Hydroxide exhibit better Zeolitic properties than Potassium Hydroxide activated Geopolymers. Also the Sodium-based solutions were cheaper than Potassium-based solutions. It has been confirmed that addition of Sodium Silicate Solution to Sodium Hydroxide enhanced the reaction rate between source material and the alkaline solution.
The sodium hydroxide solids were a technical grade in flakes form are obtained from BROS chemical industry, Tirupathi. Sodium silicate in liquid form is obtained from Meera Enterprises, Mudinepalli, Vijayawada. The specifications of sodium hydroxide flakes and sodium silicate liquid used in this project are given in Table 2.11 and Table 2.12 respectively.

**Table 2.11:** Specifications of Sodium Hydroxide Flakes

| **Minimum Assay (Acidimetric) Maximum Limits Of Impurities** | **96%** |
| --- | --- |
| Carbonate | 2% |
| Chloride | 0.1% |
| Phosphate | 0.001% |
| Silicate | 0.02% |
| Sulphate | 0.01% |
| Arsenic | 0.0001% |
| Iron | 0.005% |
| Lead | 0.001% |
| Zinc | 0.02% |

**Table 2.12:** Specification of Sodium Silicate Liquid

| S. No. | Characteristics | Specifications |
| --- | --- | --- |
| 1. | Na2O | 15.5% +_1 |
| 2. | Na2O : SiO2 Ratio | 1:2.2+_0.1 to 1:2.4+_0.1 |
| 3. | Colour | White/Black Liquid |
| 4. | Total Solid | 50% +_2% |

**Fig 2.7:** Alkaline solution

## 3. Experimental Programme
### 3.1 Materials and procurement
The complete materials used in this research work and their sources are given in Table 3.1

**Table 3.1:** Materials and their sources

| S. No | Materials | Source |
|---|---|---|
| 1. | Fly ash (Class F) | Sri Damodaram Sanjeevaiah Thermal Power Station, Nellatur |
| 2. | GGBFS | JSW Industries, Bellary |
| 3. | Sand | Locally available river sand |
| 4. | Vermiculite | Sri Venkata Padmavathi Minerals, Gudur |
| 5. | Quarry dust | Kandra, Nellore (dt.), Andhra Pradesh |
| 6. | Steel slag | Nelcast Pvt Limited, Gudur, Andhra Pradesh |
| 7. | NaOH | BROS chemical Industry, Tirupathi |
| 8. | $Na_2SiO_3$ | Meera Enterprises, Mudinepalli, Vijayawada |

### 3.2 Storage of materias

The materials were procured from respective places as mentioned in Table 3.1. Further the task ahead was the storage of these materials. The materials had to be stored in dry place, which is free from moisture, as these materials have tendency to deteriorate and lose their properties. Therefore extra care should be taken in this regard. The materials were stored in the laboratory. Hence, sufficient care was needed to keep these materials intact without any wastage at the same time attaining the optimum usage of the materials.

### 3.3 Preperation of alkaline solution

Portable water was used to prepare alkaline solution to avoid any mineral interference. The alkaline solution has to be prepared 24 hours in advance before the use. The sodium hydroxide is available in small flakes and sodium silicate is available in crystal or gel form. In this project we use the gel form of sodium silicate.

The mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of molar 'M'. For instance, NaOH solution with a concentration of 6M consisted of 6x40 = 240 grams of NaOH solids (in flake or pellet form) per liter of the solution, where 40 is the molecular weight of NaOH.

**Note:-**That the mass of NaOH solids was only a fraction of the mass of the NaOH solution, and water is the major component.

The sodium silicate is taken in the same weight as that of sodium hydroxide for preparing the solution as we are considering the ratio of sodium hydroxide to sodium silicate as 1i.e.,$NaOH:Na_2SiO3=1:1$

The solution is normally soapy in nature and even a drop of solution falls on the skin, it may cause skin irritation .Hence proper care and precautions should be taken while handling the solution. The solution should be stored in closed containers with proper labeling.

### 3.4 Calculation for the quantity of materials

In this present research work the alkaline solution of 6M is used.

We know that:

$$\text{Molarity} = \frac{\text{weight}}{\text{gram molecular weight}} \text{ per litre of solution}$$

∴Weight=Molarity × gram molecular weight, for one litre of solution.

The gram molecular weight of NaOH is 40. Hence, the weight of NaOH required to be dissolved in 1 liter of water for preparing 6M solution is 6×40=240gms.Therefore 240gms of NaOH is added in 1 liter of water. Dissolve the NaOH crystals by continuous stirring. Then an equal weight of sodium metasilicate is added as a coolent to the prepared solution. The solution has to be mixed properly up to the complete disappearance of NaOH crystals. The solutions mixed together is put aside for 24hrs before the casting of bricks.

In this experimental study, the quantities are taken using weigh batching method. Weigh batching is the method in which the quantities are taken in weights.

We have taken the weights of binder and aggregate in various proportions such as 1:2 (binder: aggregate) i.e., for 1 kg of binder we have to add 2kg of aggregate.

For geopolymer Flyash bricks, we have taken flyash and GGBFS in various proportions such as 60:40, 70:30, 80:20 and 90:10. We add the alkaline solution of 6 molarity for geopolymer flyash bricks by 0.3 times the mass of the binder.

**Example calculation**

- Dimension of the brick = 23cm×11cm×9cm
- Volume of the brick= $2.227\times10^{-3}$m$^3$
- Mass of brick =4.102kg
- Density of brick $=\frac{mass}{volume}=\frac{4.102}{2.227\times10^{-3}}$=18 kg/m$^3$

The density values for the materials are given in Table 3.2.

**Table 3.2:** Density of materials

| Materials | Density(kg/m$^3$) |
|---|---|
| Flyash | 1083 |
| Vermiculite | 386 |
| Sand | 773.7 |
| GGBFS | 1547.4 |
| Quarry Dust | 386.85 |
| Steel slag | 3000 |

**Materials required for one brick**

Mass of binder for one brick (from the density of binder) =1392.65gm

Fluid to binder ratio=0.3 i.e., $\frac{\text{FLUID}}{\text{BINDER}} = 0.3$

Mass of fluid for one brick=1392.65gms×0.3=417.795gms

Binder to aggregate ratio = $\frac{1}{2}$

Mass of the aggregate for one brick=2785.3gm

Different proportions of vermiculite, sand and quarry dust are taken to form the mass of the aggregate.

### 3.5 Casting of bricks

For any brick preparation, we have to mix the materials in dry condition and allow it for kneading for 3 to 4min.

Kneading helps in uniform mixing of materials. Then we have to add the prepared alkaline solution in the dry mix and allow it to mix for 5 to 6 min. This mixing process is done by using materials grinding machine.

**Fig 3.2:** Materials grinding machine

The kneaded mixture is then allowed to fall in the moulds of hydraulic compactor. In the hydraulic compactor there is three sets of brick moulds, each produce a brick of size 23 x 11 x 9 cm. In the moulds the mixture is compacted in three layers, for each layer 25 number of blows has to be given with the help of rammer. After the compaction, hydraulic pressure of about 1 tonne /cm$^2$ is applied on the bricks to make it dense packed. Then the bricks are collected from the hydraulic compactor on the wodden trays and it is kept for self curing.

**Fig 3.3:** Casting of bricks

### 3.6 Compressive strength test

The Geopolymer flyash bricks specimens prepared are allowed to self curing under ambient conditions and the compressive strength is determined for 3, 7 and 28 days. These bricks need not be cured in water. The compressive strength for bricks are tested by using digital compression testing machine.

**Fig 3.4:** Testing of compressive strength

Three bricks are tested at a time and the mean of the three values of these three compressive strengths are taken as the average strength.

**Fig 3.5:** Bricks before testing

## 4 Experimental results and discussion

### 4.1 Compression test results

The compressive strength of bricks was tested as described in IS 3495 (part 1). The binder percentages i.e fly ash and GGBFS percentages are taken as 60:40, 70:30, 80:20 and 90:10 respectively.

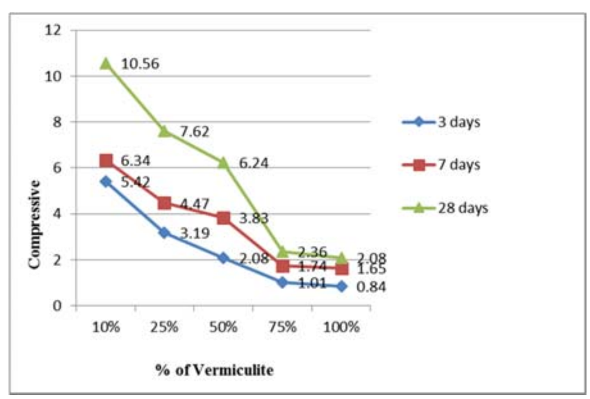
#### 4.1.1 Vermiculite as replacement of natural sand

The compressive strength of fly ash bricks for the above said binder percentages with different percentages of vermiculite are discussed below. The percentage of vermiculite for the bricks is taken in such a way that the remaining percentage in the aggregate is natural sand.

#### 4.1.1.1 for the percentages of fly ash and GGBFS as 60 and 40 respectively

**Table 4.1:** Relationship between the percentages of vermiculite and Compressive strength of self cured bricks for fly ash: GGBFS=60:40

| % of vermiculite | % of sand | Compressive strength (N/mm$^2$) | | |
|---|---|---|---|---|
| | | 3 days | 7 days | 28 days |
| 10 | 90 | 5.42 | 6.34 | 10.56 |
| 25 | 75 | 3.19 | 4.47 | 7.62 |
| 50 | 50 | 2.08 | 3.83 | 6.24 |
| 75 | 25 | 1.01 | 1.74 | 2.36 |
| 100 | 0 | 0.84 | 1.65 | 2.08 |



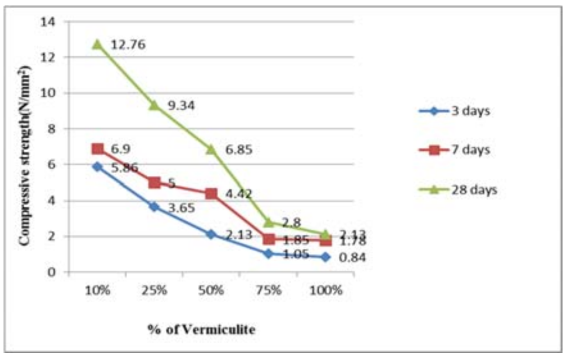

**Graph 4.1:** Relationship between the percentages of vermiculite and compressive strength of self cured bricks for fly ash : GGBFS=60:40

The maximum compressive strength of 10.56 N/mm$^2$ is obtained for this proportion at 28 days testing, the percentage of vermiculite being 10%.

#### 4.1.1.2 For the percentages of fly ash and GGBFS as 70 and 30 respectively

**Table 4.2:** Relationship between the percentages of vermiculite and compressive strength of self cured bricks for fly ash: GGBFS=70:30

| % of vermiculite | % of sand | Compressive strength (N/mm$^2$) | | |
|---|---|---|---|---|
| | | 3 days | 7 days | 28 days |
| 10 | 90 | 5.86 | 6.90 | 12.76 |
| 25 | 75 | 3.65 | 5.00 | 9.34 |
| 50 | 50 | 2.13 | 4.42 | 6.85 |
| 75 | 25 | 1.05 | 1.85 | 2.80 |
| 100 | 0 | 0.84 | 1.78 | 2.13 |



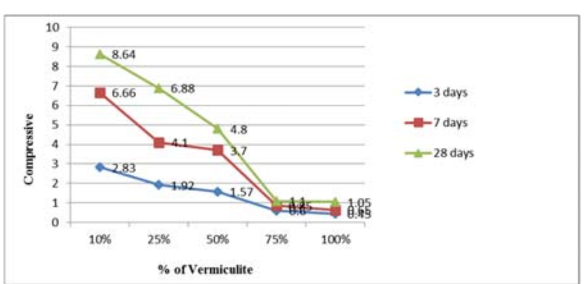

**Graph 4.2:** Relationship between the percentages of vermiculite and compressive strength of self cured bricks for flyash:GGBFS=70:30

The maximum compressive strength of 12.76 N/mm$^2$ is obtained for this proportion at 28 days testing, the percentage of vermiculite being 10%.

#### 4.1.1.3 For the percentages of fly ash and GGBFS as 80 and 20 respectively

**Table 4.3:** Relationship between the percentages of vermiculite and compressive strength of self cured bricks for fly ash: GGBFS=80:20

| % of vermiculite | % of sand | Compressive strength (N/mm$^2$) | | |
|---|---|---|---|---|
| | | 3 days | 7 days | 28 days |
| 10 | 90 | 2.83 | 6.66 | 8.64 |
| 25 | 75 | 1.92 | 4.10 | 6.88 |
| 50 | 50 | 1.57 | 3.70 | 4.80 |
| 75 | 25 | 0.60 | 0.85 | 1.10 |
| 100 | 0 | 0.45 | 0.65 | 1.05 |



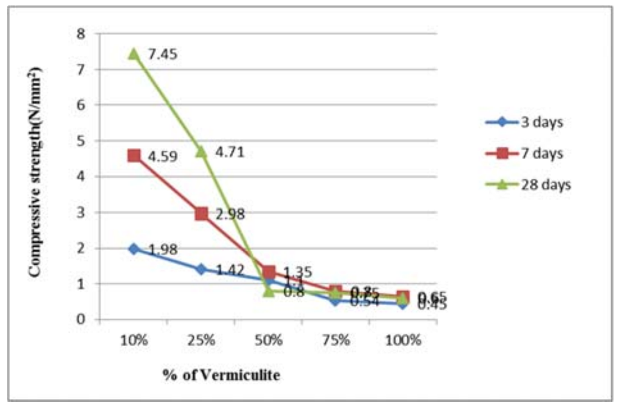

**Graph 4.3:** Relationship between the percentages of vermiculite and compressive strength of self cured bricks for flyash: GGBFS=80:20

The maximum compressive strength of 8.64 N/mm$^2$ is obtained for this proportion at 28 days testing, the percentage of vermiculite being 10%.

#### 4.1.1.4 For the percentages of fly ash and GGBFS as 90 and 10 respectively

**Table 4.4:** Relationship between the percentages of vermiculite and compressive strength of self cured bricks for flyash:GGBFS=90:10

| % of vermiculite | % of sand | Compressive strength (N/mm$^2$) | | |
|---|---|---|---|---|
| | | 3 days | 7 days | 28 days |
| 10 | 90 | 1.98 | 4.59 | 7.45 |
| 25 | 75 | 1.42 | 2.98 | 4.71 |
| 50 | 50 | 1.10 | 1.35 | 0.80 |
| 75 | 25 | 0.54 | 0.80 | 0.75 |
| 100 | 0 | 0.45 | 0.65 | 0.60 |




**Graph 4.4:** Relationship between the percentages of vermiculite and compressive strength of self cured bricks for flyash:GGBFS=90:10

The maximum compressive strength of 7.45 N/mm$^2$ for this proportion is obtained at 28 days testing, the percentage of vermiculite being 10%.

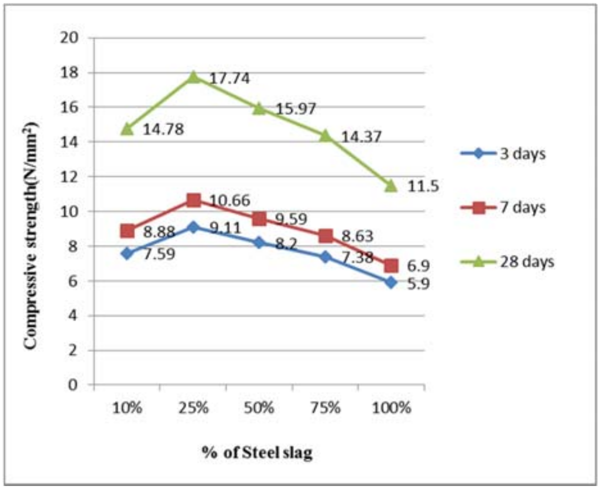
### 4.1.2 Steel slag as replacement of natural sand

The compressive strength of fly ash bricks for the above said binder percentages with different percentages of steel slag are discussed below. The percentage of steel slag for the bricks is taken in such a way that the remaining percentage in the aggregate is natural sand.

#### 4.1.2.1 For the percentages of fly ash and GGBFS as 60 and 40 respectively

**Table 4.5:** Relationship between the percentages of steel slag and compressive strength of self cured bricks for flyash: GGBFS=60:40

| % of steel slag | % of sand | Compressive strength (N/mm$^2$) | | |
|---|---|---|---|---|
| | | 3 days | 7 days | 28 days |
| 10 | 90 | 7.59 | 8.88 | 14.78 |
| 25 | 75 | 9.11 | 10.66 | 17.74 |
| 50 | 50 | 8.2 | 9.59 | 15.97 |
| 75 | 25 | 7.38 | 8.63 | 14.37 |
| 100 | 0 | 5.9 | 6.9 | 11.5 |



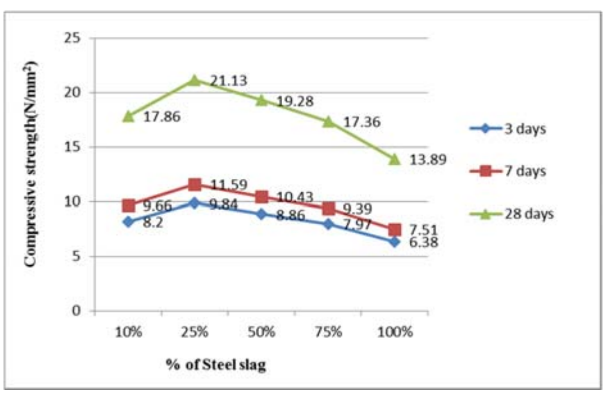

**Graph 4.5**: Relationship between the percentages of steel slag and compressive strength of self cured bricks for flyash: GGBFS=60:40

The maximum compressive strength of 17.74 N/mm$^2$ is obtained for this proportion at 28 days testing, the percentage of steel slag being 25%.

### 4.1.2.2 For the percentages of fly ash and GGBFS as 70 and 30 respectively

**Table 4.6:** Relationship between the percentages of steel slag and compressive strength of self cured bricks for flyash: GGBFS=70:30

| % of steel slag | % of sand | Compressive strength (N/mm$^2$) | | |
|---|---|---|---|---|
| | | 3 days | 7 days | 28 days |
| 10 | 90 | 8.2 | 9.66 | 17.86 |
| 25 | 75 | 9.84 | 11.59 | 21.13 |
| 50 | 50 | 8.86 | 10.43 | 19.28 |
| 75 | 25 | 7.97 | 9.39 | 17.36 |
| 100 | 0 | 6.38 | 7.51 | 13.89 |



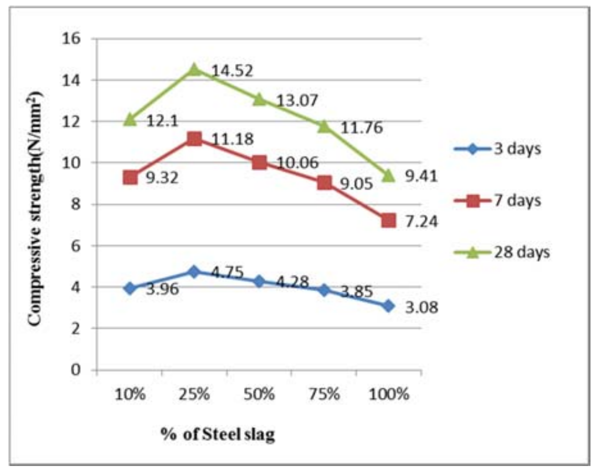

**Graph 4.6:** Relationship between the percentages of steel slag and compressive strength of self cured bricks for flyash:GGBFS=70:30

The maximum compressive strength of 21.13 N/mm$^2$ is obtained for this proportion at 28 days testing, the percentage of steel slag being 25%.

### 4.1.2.3 For the percentages of fly ash and GGBFS as 80 and 20 respectively

**Table 4.7:** Relationship between the percentages of steel slag and compressive strength of self cured bricks for flyash: GGBFS=80:20

| % of steel slag | % of sand | Compressive strength (N/mm$^2$) | | |
|---|---|---|---|---|
| | | 3 days | 7 days | 28 days |
| 10 | 90 | 3.96 | 9.32 | 12.1 |
| 25 | 75 | 4.75 | 11.18 | 14.52 |
| 50 | 50 | 4.28 | 10.06 | 13.07 |
| 75 | 25 | 3.85 | 9.05 | 11.76 |
| 100 | 0 | 3.08 | 7.24 | 9.41 |



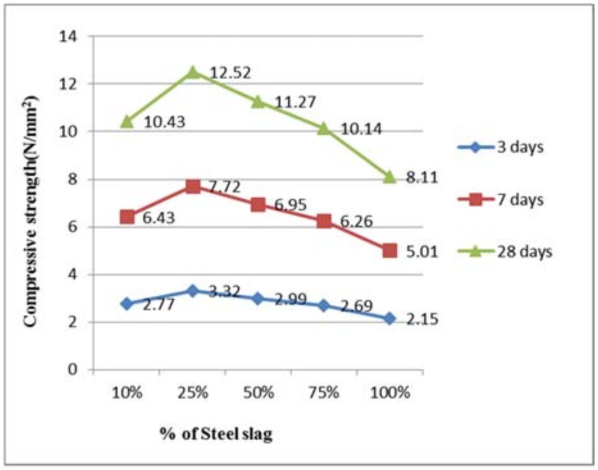

**Graph 4.7:** Relationship between the percentages of steel slag and compressive strength of self cured bricks for flyash:GGBFS=80:20

The maximum compressive strength of 14.52 N/mm$^2$ is obtained for this proportion at 28 days testing, the percentage of steel slag being 25%.

### 4.1.2.4 For the percentages of fly ash and GGBFS as 90 and 10 respectively

**Table 4.8:** Relationship between the percentages of steel slag and compressive strength of self cured bricks for fly ash : GGBFS=90:10

| % of steel slag | % of sand | Compressive strength (N/mm$^2$) | | |
|---|---|---|---|---|
| | | 3 days | 7 days | 28 days |
| 10 | 90 | 2.77 | 6.43 | 10.43 |
| 25 | 75 | 3.32 | 7.72 | 12.52 |
| 50 | 50 | 2.99 | 6.95 | 11.27 |
| 75 | 25 | 2.69 | 6.26 | 10.14 |
| 100 | 0 | 2.15 | 5.01 | 8.11 |




**Graph 4.8:** Relationship between the percentages of steel slag and compressive strength of self cured bricks for flyash:GGBFS=90:10

The maximum compressive strength of 12.52 N/mm$^2$ is obtained for this proportion at 28 days testing, the percentage of steel slag being 25%.

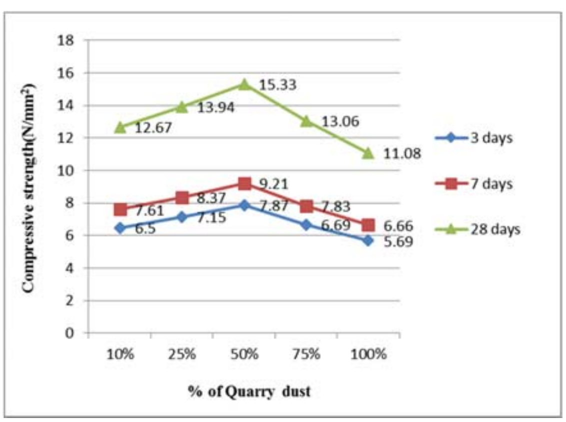
### 4.1.3 Quarry dust as replacement of natural sand

The compressive strength of fly ash bricks for the above said binder percentages with different percentages of quarry dust are discussed below. The percentage of quarry dust for the bricks is taken in such a way that the remaining percentage in the aggregate is natural sand.

#### 4.1.3.1 For the percentages of fly ash and GGBFS as 60 and 40 respectively

**Table 4.9:** Relationship between the percentages of quarry dust and compressive strength of self cured bricks for flyash:GGBFS=60:40

| % of Quarry dust | % of sand | Compressive strength (N/mm$^2$) | | |
|---|---|---|---|---|
| | | 3 days | 7 days | 28 days |
| 10 | 90 | 6.5 | 7.61 | 12.67 |
| 25 | 75 | 7.15 | 8.37 | 13.94 |
| 50 | 50 | 7.87 | 9.21 | 15.33 |
| 75 | 25 | 6.69 | 7.83 | 13.06 |
| 100 | 0 | 5.69 | 6.66 | 11.08 |



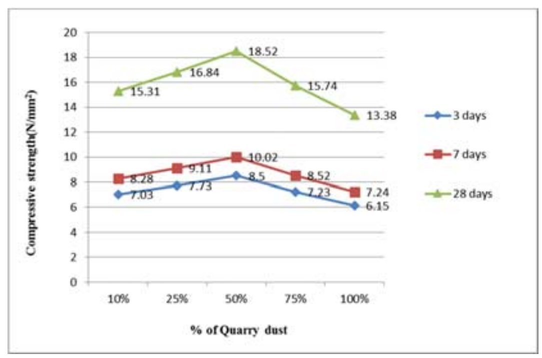

**Graph 4.9:** Relationship between the percentages of quarry dust and compressive strength of self cured bricks for fly ash: GGBFS=60:40

The maximum compressive strength of 15.33 N/mm$^2$ is obtained for this proportion at 28 days testing, the percentage of quarry dust being 50%.

#### 4.1.3.2 For the percentages of fly ash and GGBFS as 70 and 30 respectively

**Table 4.10**: Relationship between the percentages of quarry dust and compressive strength of self cured bricks for flyash: GGBFS=70:30

| % of Quarry dust | % of sand | Compressive strength (N/mm$^2$) | | |
|---|---|---|---|---|
| | | 3 days | 7 days | 28 days |
| 10 | 90 | 7.03 | 8.28 | 15.31 |
| 25 | 75 | 7.73 | 9.11 | 16.84 |
| 50 | 50 | 8.5 | 10.02 | 18.52 |
| 75 | 25 | 7.23 | 8.52 | 15.74 |
| 100 | 0 | 6.15 | 7.24 | 13.38 |



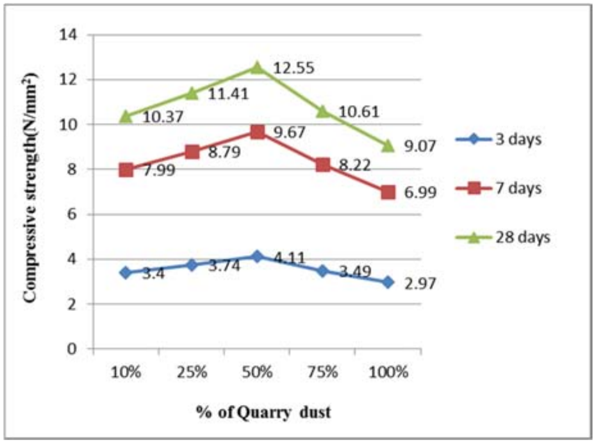

**Graph 4.10:** Relationship between the percentages of quarry dust and compressive strength of self cured bricks for flyash: GGBFS=70:30

The maximum compressive strength of 18.52 N/mm$^2$ for this proportion is obtained at 28 days testing, the percentage of quarry dust being 50%.

#### 4.1.3.3 For the percentages of fly ash and GGBFS as 80 and 20 respectively

**Table 4.11:** Relationship between the percentages of quarry dust and compressive strength of self cured bricks for flyash:GGBFS=80:20

| % of Quarry dust | % of sand | Compressive strength (N/mm$^2$) | | |
|---|---|---|---|---|
| | | 3 days | 7 days | 28 days |
| 10 | 90 | 3.4 | 7.99 | 10.37 |
| 25 | 75 | 3.74 | 8.79 | 11.41 |
| 50 | 50 | 4.11 | 9.67 | 12.55 |
| 75 | 25 | 3.49 | 8.22 | 10.61 |
| 100 | 0 | 2.97 | 6.99 | 9.07 |



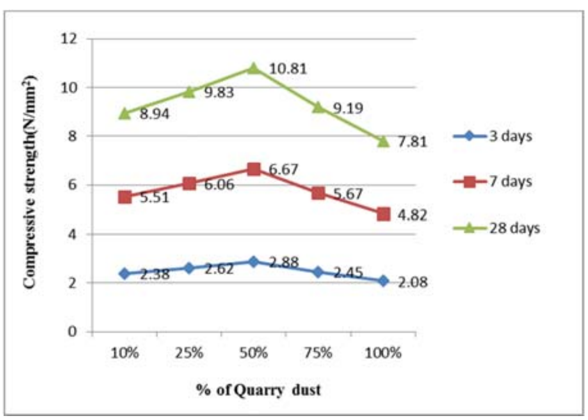

**Graph 4.11:** Relationship between the percentages of quarry dust and compressive strength of self cured bricks for flyash: GGBFS=80:20

The maximum compressive strength of 8.64 N/mm$^2$ for this proportion is obtained at 28 days testing, the percentage of quarry dust being 50%.

### 4.1.1.4 For the percentages of fly ash and GGBFS as 90 and 10 respectively

**Table 4.12:** Relationship between the percentages of quarry dust and compressive strength of self cured bricks for flyash: GGBFS=90:10

| % of Quarry dust | % of sand | Compressive strength (N/mm$^2$) | | |
|---|---|---|---|---|
| | | 3 days | 7 days | 28 days |
| 10 | 90 | 2.38 | 5.51 | 8.94 |
| 25 | 75 | 2.62 | 6.06 | 9.83 |
| 50 | 50 | 2.88 | 6.67 | 10.81 |
| 75 | 25 | 2.45 | 5.67 | 9.19 |
| 100 | 0 | 2.08 | 4.82 | 7.81 |




**Graph 4.12:** Relationship between the percentages of quarry dust and compressive strength of self cured bricks for flyash: GGBFS=90:10

The maximum compressive strength of 10.81 N/mm$^2$ is obtained for this proportion at 28 days testing, the percentage of quarry dust being 50%.

## 4.3 Discussion on test results
### 4.3.1 Compression test
### 4.3.1.1 Vermiculite as replacement of natural sand
- With increase in the percentage of vermiculite, compressive strength gradually decreases.
- The highest compressive strength is obtained at 10% of vermiculite for the percentage of fly ash and GGBFS being 70 and 30 respectively.
- The least compressive strength is obtained at 100% of vermiculite for the percentage of fly ash and GGBFS being 90 and 10 respectively.

### 4.3.1.2 Steel slag as replacement of natural sand
- With increase in the percentage of steel slag up to 25% the compressive strength gradually increases and then decreases.
- The highest compressive strength is obtained at 25% of steel slag for the percentage of fly ash and GGBFS being 70 and 30 respectively.
- The least compressive strength is obtained at 100% of steel slag for the percentage of fly ash and GGBFS being 90 and 10 respectively.

### 4.3.1.3 Quarry dust as replacement of natural sand
- With increase in the percentage of quarry dust up to 50% the compressive strength gradually increases and then decreases.
- The highest compressive strength is obtained at 50% of quarry dust for the percentage of fly ash and GGBFS being 70 and 30 respectively.
- The least compressive strength is obtained at 100% of quarry dust for the percentage of fly ash and GGBFS being 90 and 10 respectively.

### 4.3.1.4 For the percentages of fly ash and GGBFS as 60 and 40 respectively For 3 days
- The compressive strength obtained at 25% of steel slag is 15.75% greater than that of 50% of quarry dust and 68% greater than that of 10% of vermiculite.
- The compressive strength obtained at 50% of quarry dust is 45.2% greater than that of 10% of vermiculite.
- The higher compressive strength using vermiculite is 6.45 times to its least compressive strength.
- The higher compressive strength using steel slag is 1.54 times to its least compressive strength.
- The higher compressive strength using quarry dust is 1.38 times to its least compressive strength.

➢ **For 7 days**
- The compressive strength obtained at 25% of steel slag is 15.74% greater than that of 50% of quarry dust and 68.14% greater than that of 10% of vermiculite.
- The compressive strength obtained at 50% of quarry dust is 45.3% greater than that of 10% of vermiculite.
- The higher compressive strength using vermiculite is 3.84 times to its least compressive strength.
- The higher compressive strength using steel slag is 1.54 times to its least compressive strength.
- The higher compressive strength using quarry dust is 1.38 times to its least compressive strength.

➢ **For 28 days**
- The compressive strength obtained at 25% of steel slag is 15.72% greater than that of 50% of quarry dust and 68% greater than that of 10% of vermiculite.
- The compressive strength obtained at 50% of quarry dust is 45.17% greater than that of 10% of vermiculite.
- The higher compressive strength using vermiculite is 5.07 times to its least compressive strength.

- The higher compressive strength using steel slag is 1.54 times to its least compressive strength.
- The higher compressive strength using quarry dust is 1.38 times to its least compressive strength.

**4.3.1.5 For the percentages of fly ash and GGBFS as 70 and 30 respectively**

- **For 3 days**
- The compressive strength obtained at 25% of steel slag is 15.76% greater than that of 50% of quarry dust and 67.9% greater than that of 10% of vermiculite.
- The compressive strength obtained at 50% of quarry dust is 45% greater than that of 10% of vermiculite.
- The higher compressive strength using vermiculite is 6.97 times to its least compressive strength.
- The higher compressive strength using steel slag is 1.54 times to its least compressive strength.
- The higher compressive strength using quarry dust is 1.38 times to its least compressive strength.

- **For 7 days**
- The compressive strength obtained at 25% of steel slag is 15.67% greater than that of 50% of quarry dust and 67.9% greater than that of 10% of vermiculite.
- The compressive strength obtained at 50% of quarry dust is 45.21% greater than that of 10% of vermiculite.
- The higher compressive strength using vermiculite is 3.88 times to its least compressive strength.
- The higher compressive strength using steel slag is 1.54 times to its least compressive strength.
- The higher compressive strength using quarry dust is 1.38 times to its least compressive strength.

- **For 28 days**
- The compressive strength obtained at 25% of steel slag is 15.71% greater than that of 50% of quarry dust and 67.9% greater than that of 10% of vermiculite.
- The compressive strength obtained at 50% of quarry dust is 45.14% greater than that of 10% of vermiculite.
- The higher compressive strength using vermiculite is 5.99 times to its least compressive strength.
- The higher compressive strength using steel slag is 1.54 times to its least compressive strength.
- The higher compressive strength using quarry dust is 1.38 times to its least compressive strength.

**4.3.1.6 For the percentages of fly ash and GGBFS as 80 and 20 respectively**

- **For 3 days**
- The compressive strength obtained at 25% of steel slag is 15.57% greater than that of 50% of quarry dust and 67.84% greater than that of 10% of vermiculite.
- The compressive strength obtained at 50% of quarry dust is 45.23% greater than that of 10% of vermiculite.
- The higher compressive strength using vermiculite is 6.29 times to its least compressive strength.
- The higher compressive strength using steel slag is 1.54 times to its least compressive strength.
- The higher compressive strength using quarry dust is 1.38 times to its least compressive strength.

- **For 7 days**
- The compressive strength obtained at 25% of steel slag is 15.61% greater than that of 50% of quarry dust and 67.87% greater than that of 10% of vermiculite.
- The compressive strength obtained at 50% of quarry dust is 45.19% greater than that of 10% of vermiculite.
- The higher compressive strength using vermiculite is 10.24 times to its least compressive strength.
- The higher compressive strength using steel slag is 1.54 times to its least compressive strength.
- The higher compressive strength using quarry dust is 1.38 times to its least compressive strength.

- **For 28 days**
- The compressive strength obtained at 25% of steel slag is 15.69% greater than that of 50% of quarry dust and 68% greater than that of 10% of vermiculite.
- The compressive strength obtained at 50% of quarry dust is 45.25% greater than that of 10% of vermiculite.
- The higher compressive strength using vermiculite is 8.23 times to its least compressive strength.
- The higher compressive strength using steel slag is 1.54 times to its least compressive strength.
- The higher compressive strength using quarry dust is 1.38 times to its least compressive strength.

**4.3.1.7 For the percentages of fly ash and GGBFS as 90 and 10 respectively**

- **For 3 days**
- The compressive strength obtained at 25% of steel slag is 15.27% greater than that of 50% of quarry dust and 67.68% greater than that of 10% of vermiculite.
- The compressive strength obtained at 50% of quarry dust is 45.45% greater than that of 10% of vermiculite.
- The higher compressive strength using vermiculite is 4.4 times to its least compressive strength.
- The higher compressive strength using steel slag is 1.54 times to its least compressive strength.
- The higher compressive strength using quarry dust is 1.38 times to its least compressive strength.

- **For 7 days**
- The compressive strength obtained at 25% of steel slag is 15.74% greater than that of 50% of quarry dust and 68.19% greater than that of 10% of vermiculite.
- The compressive strength obtained at 50% of quarry dust is 45.31% greater than that of 10% of vermiculite.
- The higher compressive strength using vermiculite is 7.06 times to its least compressive strength.
- The higher compressive strength using steel slag is 1.54 times to its least compressive strength.
- The higher compressive strength using quarry dust is 1.38 times to its least compressive strength.

- **For 28 days**
- The compressive strength obtained at 25% of steel slag is 15.81% greater than that of 50% of quarry dust and 68% greater than that of 10% of vermiculite.
- The compressive strength obtained at 50% of quarry dust is 45.1% greater than that of 10% of vermiculite.
- The higher compressive strength using vermiculite is 12.41 times to its least compressive strength.
- The higher compressive strength using steel slag is 1.54 times to its least compressive strength.
- The higher compressive strength using quarry dust is 1.38 times to its least compressive strength.

## 5. Conclusion

As per the codal provisions of IS 12894:2002, the minimum compressive strength for any class of fly ash brick should not be less than 3.5 $N/mm^2$. Based on the minimum compressive strength criteria the following conclusions were drawn.

- The maximum compressive strengths are obtained for the fly ash and GGBFS percentages of 70 and 30respectively, irrespective of the alternative material for natural sand.

### 5.1 Vermiculite

- The vermiculite can be used up to 50% replacement of natural sand for the percentages of fly ash and GGBFS being 60:40, 70:30 and 80:20 and up to 25% replacement for the percentages of fly ash and GGBFS being 90:10.
- The higher compressive strengths are obtained at 10% of vermiculite.
- The best compressive strength using vermiculite is 12.76 $N/mm^2$.

### 5.2 Quarry dust

- The quarry dust can be used up to 100% replacement of natural sand for all the percentages of fly ash and GGBFS.
- The higher compressive strengths are obtained at 50% of quarry dust.
- The best compressive strength using quarry dust is 18.52 $N/mm^2$.

### 5.3 Steel slag

- The steel slag can be used up to 100% replacement of natural sand for all the percentages of fly ash and GGBFS.
- The higher compressive strengths are obtained at 25% of steel slag.
- The best compressive strength using steel slag is 21.13 $N/mm^2$.

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