*Journal of Engineering and Technological Advances (JETA)*
https://jeta.segi.edu.my/index.php/segi
*2023 Vol. 8 No. 1*

# STUDY OF COMPRESSIVE STRENGTH OF BLENDED FLY ASH WITH GROUND GRANULATED BLAST FURNACE SLAG AND QUARTZ POWDER BASED GEOPOLYMER MORTAR AND BLOCKS

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**Abstract:** This study investigates the use of industrial wastes like Fly Ash (FA), Ground Granulated Blast-furnace Slag (GGBS), and Quartz Powder (QP) as alternatives to cement, and Copper Slag (CS) as fine aggregate in Geopolymer blocks (GPB). The mix ratio of 1:3 one part of the binder and 3 parts of copper slag, 8M, and 10M of NaOH, and $Na_2SiO_3$ solutions are used as Alkaline Activator Solution (AAS). Two types of Geopolymer blocks GPB1 (Mortar Blocks) and GPB2 (Aerated Geopolymer Blocks) are produced. The binders of FA, GGBS, QP, and fine aggregate of CS are tested to find fineness, specific gravity, and absorption capacity. A suitable percentage of binders and CS are added together and dry-mixed in a mortar mixing machine for each mix separately. The fresh mix of GPB1 and GPB2 is placed in the moulds, compacted and placed in an oven at 60°C-70°C for 24 hours. The compressive strength of GPB1 and GPB2 mixes are found performing compression testing, the maximum compressive strength of 82.50 MPa is achieved when 100% of GGBS in mortar and 10.54MPa is achieved when 70% of FA and 30% of QP is used. Aerated Geopolymer block GPB2 M1 shows a better compressive strength of 12.66 MPa in oven curing after 24 hours, and 10.95MPa after ambient curing for 7 days. The increase in GGBS in GPB1 Mortar1 increases the compressive strength, and the increase in QP in GPB1 Mortar2 increases the compressive strength but it is very low as compared to GPB1 Mortar1.

Keywords: Industrial wastes; Fly Ash; GGBS; Quartz Powder; Copper Slag; Geopolymer mortar; Geopolymer blocks; Compressive Strength.

## 1. Introduction

Cement and bricks are the most consumed materials in building construction. Cement and bricks are extensively used for buildings, both load-bearing and framed structures, but they contribute to global warming. The bricks are burnt in kilns using large amounts of firewood. As the demand for bricks rises so does the demand for firewood resulting in deforestation, further impacting the environment by emitting $CO_2$. Cement is used for concreting, plastering, masonry, and manufacturing of blocks like Autoclaved Aerated Cement (AAC) blocks, Hollow blocks, and Solid blocks. These blocks are produced in large amounts in recent times and they have replaced the normal country bricks. Among these materials, the production of cement requires a large amount of energy and the process also pollutes the environment. The cement manufacturing industries release approximately 0.7-1.1 tons of $CO_2$ for producing one ton of cement (Jeeva Chithambaram et al., 2019). Filler materials such as natural sand and coarse aggregates can be obtained by deploying natural non-renewable resources. Also, there is currently a shortage of these natural raw materials for concrete. In order to avoid these issues, utilization of industrial waste products such as FA, GGBS, QP, and CS with AAS is suggested to make Geopolymer Mortar and Geopolymer blocks.

The word "Geopolymer" was introduced by Professor Davidovits in 1978 (Davidovits, 1981). The use of Geopolymer binders, mortar, and Geopolymer blocks reduces natural source materials required for producing cement, mortar, bricks, and blocks. Further, this alternative process reduces the carbon footprint and is also an economically efficient method (Prashant et al., 2016; Pratik et al., 2016; Sanjayan et al., 2015).

## 2. Materials and Methods

### 2.1 FlyAsh

Fly ash, shown in **Figure 1**, is a waste material that is obtained from the burning of coal as fuel in thermal power plants. Fly ash is a very fine material of sizes 45μm and less. Usually, it is dumped on land as waste and now, it is used as a binding material blended with cement, because of its very fine sizes and its Silica content. The use of Fly Ash in construction reduces the demand for cement and reduces cement production and the resultant carbon dioxide emissions as well. Fly Ash is available in the grades Class C and Class F, Fly ash Class C contains more Calcium Oxide content than Fly Ash Class F. So, the use of Fly ash Class C attains a rapid setting. In this study, Fly Ash Class F procured from the nearest sources with a specific gravity of 2.32 is used for this study (Rohit & Mamatha, 2015; Guru Jawahar & Mounika 2016).

**Figure 1.** Fly Ash

### 2.2 Ground Granulated Blast Furnace Slag

GGBS, shown in **Figure 2**, is a fine powder-like material and it is produced from the production of steel. When the purification of molten iron is done, the floating matter of impurities is collected, cooled, and crushed into a fine powder named GGBS, which contains high Calcium Oxide. GGBS obtained from local suppliers for this study contains a specific gravity of 2.82 (Islam et al., 2014).

**Figure 2.** GGBS

### 2.3 Quartz Powder

Quartz Powder, shown in **Figure 3**, is a natural source material obtained by crushing Quartz stones in quarries with a specific gravity of 2.46.

**Figure 3.** Quartz Powder

### 2.4 Copper Slag

Copper slag, shown in **Figure 4**, is also an industrial by-product that is obtained from copper industries during the extraction of copper by smelting. The impurity which floats on the molten liquid during smelting is separated and treated with water to form granules. These granules are dumped as waste on land. This waste copper slag is used as fine aggregate in place of natural fine aggregates like river sand, M-sand, and P-sand. The copper slag used in this study is procured from nearest sources with a specific gravity of 3.64 and a Fineness Modulus of 4.56. According to the sieve analysis, the copper slag confirms to zone II as per IS383-2016 (Mahendran & Arunachelam, 2015, 2016; IS 383, 2016).

**Figure 4.** Copper Slag

## 2.5 Alkaline Activator Solution

An Alkaline Activator Solution (AAS) is prepared by mixing sodium hydroxide (NaOH) solution and sodium silicate ($Na_2SiO_3$) solution. When both solutions are mixed, it starts to liberate large amounts of heat and it increases the temperature of the AAS. So, it is recommended to set aside the AAS for 24 hours to reduce its temperature to normal room temperature.

## 2.6 Preparation of Alkaline Activator Solution

Sodium hydroxide pellets are dissolved in distilled water to make 8 and 10 molar solutions of NaOH separately. The Alkaline Activator Solution is made by thoroughly mixing the prepared NaOH solution and Sodium silicate solution ($Na_2SiO_3$) in the ratio of 1:1.5. (i.e.,) the amount of Sodium silicate taken is 1.5 times the amount of NaOH taken for GPB 2 (Aerated Geopolymer Blocks). Similarly, a ratio of 1:2 is taken for GPB 1 (Mortar) Blocks. The amount of AAS is obtained from (AAS / binder) ratio = 0.45, and is fixed for casting all the proportions (Rajamane & Jayalakshmi, 2014; Elyamany et al, 2018; Muthu Kumar & Ramamurthy, 2017; Wongkeo et al., 2019).

## 2.7 Mix Design

### 2.7.1 Geopolymer Blocks (GPB1) (Mortar Blocks)

The mix ratio for mortar preparation used is 1:3 with one part of the binding material and 3 parts of copper slag weighed accurately before loading into the mortar mixer. The dry mixing of these materials was done for a period of 2-3 minutes as shown in **Figure 5** and then, the Alkaline Activator Solution containing one part of 8M sodium hydroxide solution (NaOH) and two parts of Sodium silicate solution ($Na_2SiO_3$) is added to the dry mix as shown in **Figure 6** and the entire materials are mixed for a period of 3-5 minutes in a mortar mixing machine. The various mix proportions are given in the Table 1 and Table 2 below:

Table 1**.** Mix Proportions of Geopolymer Blocks 1 (Mortar 1)

(Fly Ash F with GGBS)

| **Sl. No** | **Mix ID** | **Proportion of Binders** | | **Proportion of Fine Aggregate (CS)** | **AAS / Binder ratio** |
|---|---|---|---|---|---|
| | | **Fly Ash Class F** | **GGBS** | | |
| 1 | GPB1 M10 | 100% | 0% | 300% | 0.45 |
| 2 | GPB1 M11 | 75% | 25% | 300% | 0.45 |
| 3 | GPB1 M12 | 50% | 50% | 300% | 0.45 |
| 4 | GPB1 M13 | 25% | 75% | 300% | 0.45 |
| 5 | GPB1 M14 | 0% | 100% | 300% | 0.45 |

Table 2**.** Mix Proportions of Geopolymer Blocks 1 (Mortar 2)

(Fly Ash F with Quartz Powder)

| **Sl. No** | **Mix ID** | **Proportion of Binders** | | **Proportion of Fine Aggregate (CS)** | **AAS / Binder ratio** |
|---|---|---|---|---|---|
| | | **Fly Ash Class F** | **QP** | | |
| 1 | GPB1 M20 | 100% | 0% | 300% | 0.45 |
| 2 | GPB1 M21 | 90% | 10% | 300% | 0.45 |
| 3 | GPB1 M22 | 80% | 20% | 300% | 0.45 |
| 4 | GPB1 M23 | 70% | 30% | 300% | 0.45 |

### 2.7.2 Geopolymer Blocks (GPB2) (Aerated Geopolymer Blocks)

Fly Ash Class F and GGBS were used to produce Aerated Geopolymer blocks. NaOH pellets were dissolved in distilled water to make a 10-Molar solution of NaOH. Hydration of NaOH is an exothermic reaction, so it is kept at atmospheric temperature for 24 hours to cool down. Then $Na_2SiO_3$ solution is mixed with NaOH solution in the ratio of 1.5:1 to make an Alkaline Activator Solution (AAS). For the aeration of the Specimen, Aluminium Powder is used as 0.03 % to 0.06 % of the weight of the binder (Ducman & Korat, 2016). 25% GGBS & 75 % FA was thoroughly dry mixed with Aluminium powder. A suitable amount of soap oil and AAS is added to the dry mix to make a fresh wet mix. The mix proportions are given in the Table 3 below:

Table 3**.** Mix proportions of Geopolymer Blocks 2

(Aerated Geopolymer Blocks)

| **Sl. No** | **Mix ID** | **Proportion of Binders (GGBS)** | **Proportion of Fine Aggregate (FA)** | **Proportion of Aluminium Powder** | **AAS / Binder ratio** |
|---|---|---|---|---|---|
| 1 | GPB2 M1 | 25% | 75% | 0.03% | 0.45 |
| 2 | GPB2 M2 | 25% | 75% | 0.045% | 0.45 |
| 3 | GPB2 M3 | 25% | 75% | 0.06% | 0.45 |

## 2.8 Casting and Curing of Geopolymer Blocks

### 2.8.1 Geopolymer Blocks (GPB1) (Mortar Blocks)

The fresh wet mix is poured into mortar moulds of size 70.6mm x 70.6mm x 70.6mm, and then it is vibrated using a table vibrator as shown in **Figure 7** for a few minutes. Then, 3 casted cubes for each mix proportions are kept in the oven for 24 hours at 70ºC. After that, the samples are de-moulded for testing.

### 2.8.2 Geopolymer Blocks (GPB 2) (Aerated Geopolymer Blocks)

The fresh wet mix is poured into moulds of size 70.6mm x 70.6mm x 70.6mm, and then it is vibrated using a table vibrator for a few minutes. Then, 3 casted cubes for each mix proportions are kept in the oven for 24 hours at 60ºC (Vijai et al., 2010; Mohd Mustafa Al Bakri Abdullah et al., 2014) as shown in **Figure 8**. Another set of the same number of samples for each proportion is kept in ambient curing for up to 7 days as shown in **Figure 9**. After that, the samples are de-moulded for testing.

**Figure 5.** Preparation of dry mix

**Figure 6.** Preparation of wet mix

**Figure 7.** Compaction of Mortar using table Vibrator

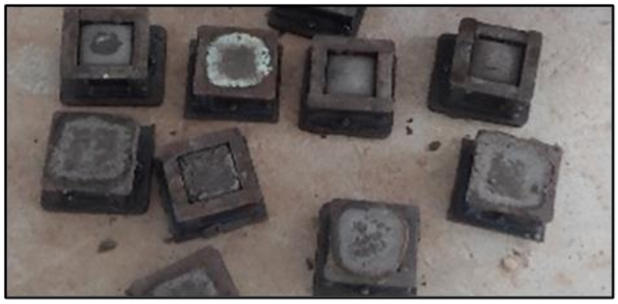

**Figure 8.** Oven-cured specimens

**Figure 9.** Ambient Curing

## 3. Results and Discussion

### 3.1 Compressive Strength

The oven-cured and ambient samples are tested in a digital compression testing machine shown in **Figure 10**. The compression test is conducted as per Indian Standard (IS 6441 Part V, 1972) to find the maximum compressive strength of the Geopolymer Mortar Blocks and Aerated Geopolymer Blocks in compression.

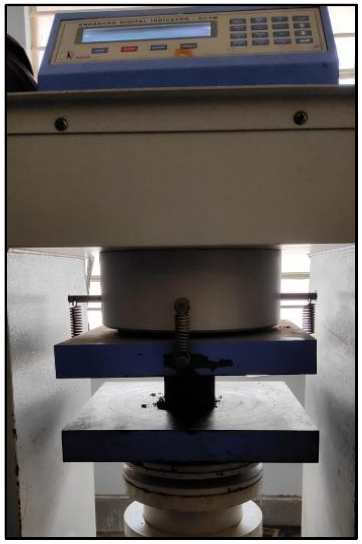

**Figure 10.** Compression testing of sample in digital compression testing machine

The compressive strength of Geopolymer Blocks 1 (Mortar 1 Fly Ash F with GGBS) as mentioned in **Table 4** and **Figure 11** increases with increase in the percentage of GGBS. Adopt the Fly Ash and GGBS proportions based on the requirement of compressive strength.

**Table 4.** Compressive Strength of Geopolymer Blocks 1 (Mortar 1 Fly Ash F with GGBS)

| **Sl. No** | **Mix ID** | **Proportion of Binders** | | **Proportion of Fine Aggregate (CS)** | **Average Compressive Strength in MPa** |
|---|---|---|---|---|---|
| | | **Fly Ash Class F** | **GGBS** | | |
| 1 | GPB1 M10 | 100% | 0% | 300% | 4.71 |
| 2 | GPB1 M11 | 75% | 25% | 300% | 19.03 |
| 3 | GPB1 M12 | 50% | 50% | 300% | 36.82 |
| 4 | GPB1 M13 | 25% | 75% | 300% | 60.32 |
| 5 | GPB1 M14 | 0% | 100% | 300% | 82.50 |

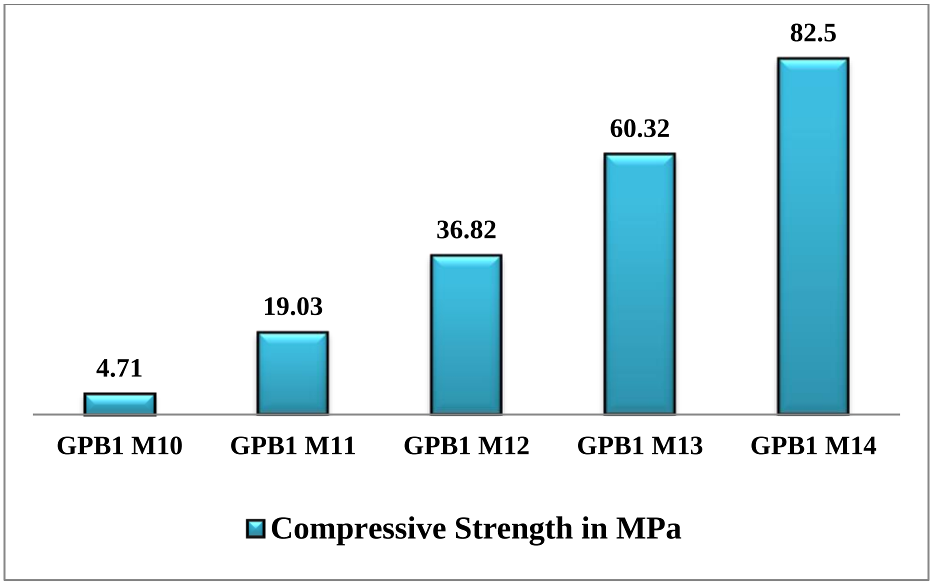


**Figure 11.** Compressive Strength of Geopolymer Blocks 1 (Mortar 1 Fly Ash F with GGBS)

The compressive strength of Geopolymer Blocks 1 (Mortar 2 Fly Ash F with Quartz Powder) as mentioned in **Table 5** and **Figure 12** increases with increase in the percentage of Quartz Powder, but it attained lesser compressive strength than the GGBS.

**Table 5.** Compressive Strength of Geopolymer Blocks 1
(Mortar 2 Fly Ash F with Quartz Powder)

| Sl. No | Mix ID | Proportion of Binders | | Proportion of Fine Aggregate (CS) | Average Compressive Strength in MPa |
|---|---|---|---|---|---|
| | | Fly Ash Class F | QP | | |
| 1 | GPB1 M20 | 100% | 0% | 300% | 4.71 |
| 2 | GPB1 M21 | 90% | 10% | 300% | 8.83 |
| 3 | GPB1 M22 | 80% | 20% | 300% | 9.96 |
| 4 | GPB1 M23 | 70% | 30% | 300% | 10.54 |

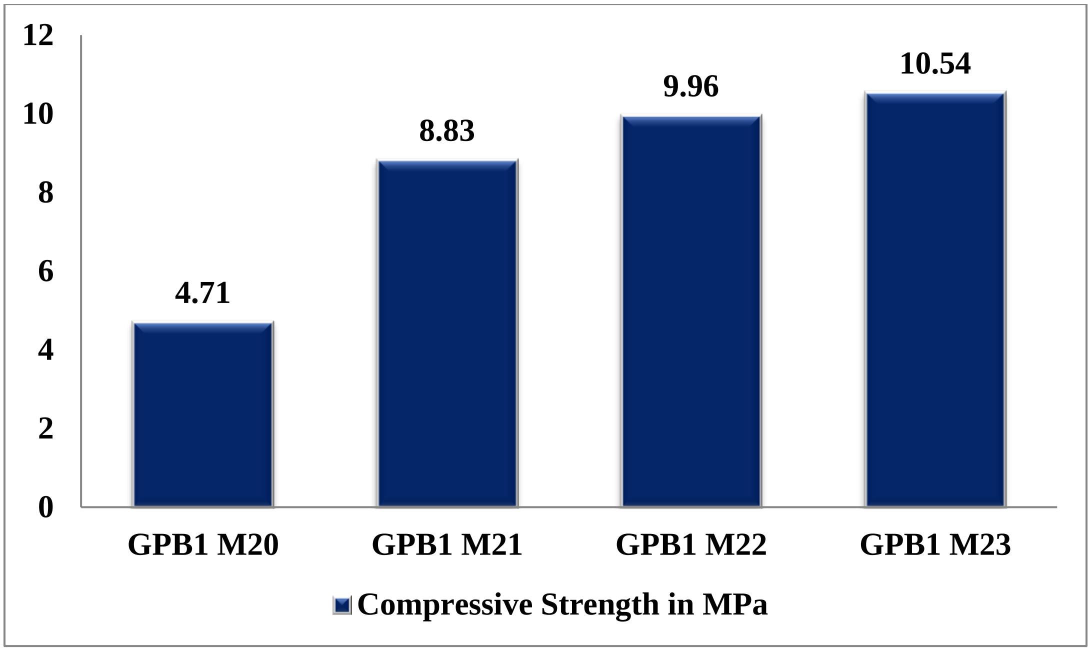


**Figure 12.** Compressive Strength of Geopolymer Blocks 1
(Mortar 2 Fly Ash F with Quartz Powder)

Compressive Strength of Geopolymer Blocks 2 (Aerated Geopolymer Blocks) reported in **Table 6** and **Figure 13Figure *13*.** Compressive Strength of Geopolymer Blocks 2 (Aerated Geopolymer Blocks) reduced with the increase in percentage of Aluminium Powder. The ambient cured samples reached 84-86% of compressive strength of the oven cured samples. An optimum level of 0.03% of Aluminium powder is used to produce light weight aerated concrete with better compressive strength as reported in **Figure 14**.

**Table 6.** Compressive Strength of Geopolymer Blocks 2
(Aerated Geopolymer Blocks)

| Sl. No | Mix ID | Proportion of Binders (GGBS) | Proportion of Fine Aggregate (FA) | Proportion of Aluminium Powder | Average Compressive Strength in MPa | |
|---|---|---|---|---|---|---|
| | | | | | Oven-Cured Specimen | Ambient Cured Specimen |

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | GPB2 M1 | 25% | 75% | 0.03% | 12.66 | 10.95 |
| 2 | GPB2 M2 | 25% | 75% | 0.045% | 6.05 | 5.11 |
| 3 | GPB2 M3 | 25% | 75% | 0.06% | 4.47 | 3.77 |

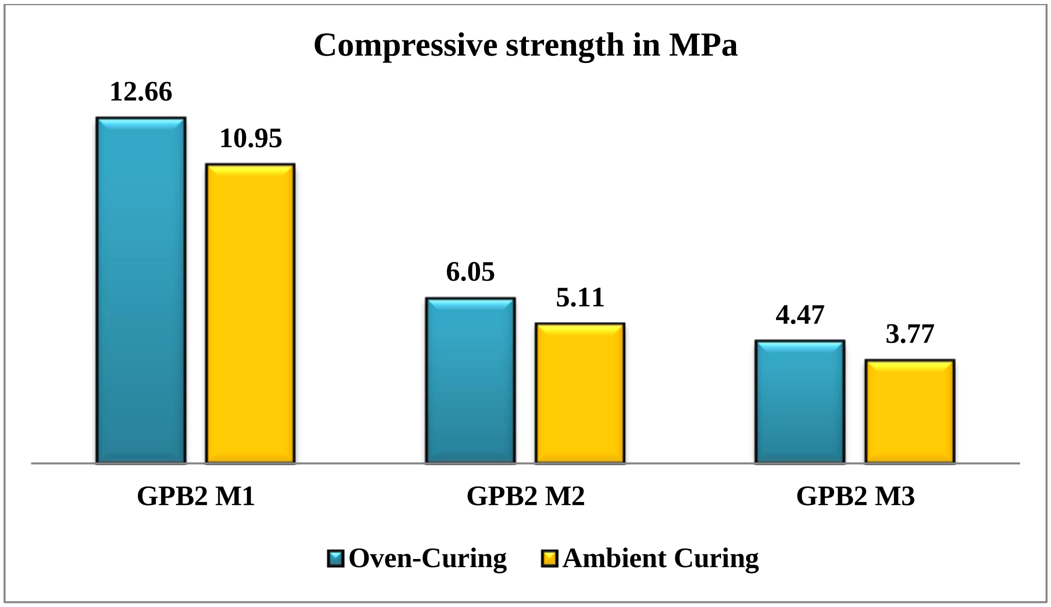


**Figure 13.** Compressive Strength of Geopolymer Blocks 2 (Aerated Geopolymer Blocks)

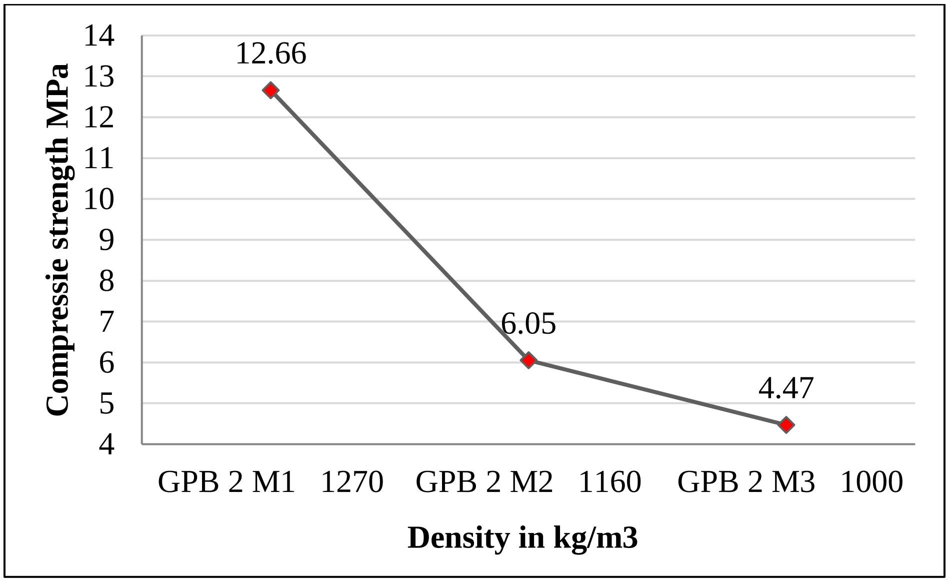


**Figure 14.** Compressive Strength Vs Density of Geopolymer Blocks 2 (Aerated Geopolymer Blocks)

## 4. Conclusion

The maximum compressive strength of 82.50 MPa is achieved when 100% of GGBS binder is used in GPB1 M14 mix and 10.54MPa is achieved when 30% of Quartz Powder is used in GPB1 M23 mix. In Aerated Geopolymer Block GPB 2 M1 shows better compressive strength of 12.66 MPa in oven curing after 24 hours and 10.95MPa in ambient curing for 7 days. The increase in GGBS in GPB1 Mortar 1 increases the compressive strength, and the increase in QP in GPB1 Mortar 2 also increases the compressive strength, but it is very low as compared to GPB 1 Mortar 1 samples.  The GGBS is used as binder in Geopolymer concrete directly or blended with FA and it produces better compressive strength. When 100% of GGBS is used as a binder, the mix sets at a rapid rate and affects the mixing and casting process. An optimum level of 50% to 80% GGBS is used in the preparation of mortar samples. The increase in the percentages of Quartz powder in mortar leads to a bulging effect during the curing process because of the presence of high silica. Further, this study extends the chemical composition of each binder and the resultant change when it is blended with Fly Ash to find the exact reasons for the above-reported problems. The aerated Geopolymer blocks achieve less gain in weight as the percentage of Aluminium powder increases, but it reduces the compressive strength. Aminimum of 0.03% of Aluminium powder produces better compressive strength. This study suggests the ambient curing of samples used for normal cases of production and oven curing for the rapid rate of production of the aerated Geopolymer Blocks.

**Acknowledgement**

The author Balamurali R T thanks The Gandhigram Rural Institute (Deemed to be University), Gandhigram 624302, Dindigul District, Tamil Nadu, India for the financial support through the seed money grant for the completion of this study.  Also, the authors jointly thank SEGi University, Malaysia for this opportunity.

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