

# **Optimizing Fly-Ash Cement Ratios for Load-Bearing Cement Blocks: Technical Considerations and Recommendations**

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**Abstract:** One of the global tendencies regarding the possibility of using fly ash as a cement mortar ingredient, to save the amount of cement being consumed, is to conserve the environment and maintain the ecosystem. This research sought to establish the optimum quantity of fly ash that should be included in cement mortar so as to obtain the necessary strength. The blocks were tested on their compressive strength, water absorption, and density in different treatments at specific intervals of 07 days to 28 days. There was a very high correlation between the fly ash content of cement mortar blocks and the compressive strength, water absorption, and density using statistical analysis. According to the test results, the compressive strength and density of the blocks produced decreased progressively as the amount of fly ash was increased, whereas the water absorbed in the blocks was higher. The application of fly ash up to 40 percent increases water absorption to within an acceptable limit of 15 percent and reduces compressive strength below the limit of 200 kg/cm<sup>2</sup> of load-bearing cement blocks. The mixing of fly-ash concrete block should not exceed 40 percent fly ash in cement mortar.

**Keywords:** Fly-ash, Compressive Strength, Unit Weight, Mortar Blocks, Water Absorption.

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## **1. Introduction**

Cement is a crucial component in construction due to its ability to enhance the strength and durability of structures, ultimately increasing their value. Cement producers prioritize finding cost-effective and eco-friendly materials to produce their products. To reduce the cost of mortar and concrete, they continuously test locally available materials in laboratories to achieve the desired aggregate ratio and ingredients, resulting in satisfactory trials. [1]. In the current situation, there is a heightened focus on using cost-effective and eco-friendly materials. Various studies have shown that the production of cement contributes significantly to global warming and leads to a more significant temperature increase. The cement manufacturing industry is recognized as a significant source of pollution worldwide, and there is an urgent need to enhance its sustainability. Reducing the carbon dioxide (CO<sub>2</sub>) emissions generated during cement production is a primary focus for this industry. To address this challenge, there is growing interest in using alternative materials as clinker replacements, and this practice is becoming

increasingly popular. Several studies have highlighted the potential benefits of incorporating such materials to improve the sustainability of the cement industry [2, 3, 4 & 5]. In addition, by saving energy, cheaper and high-class materials have been obtained along with improved economy [6].

Fly ash is a pozzolanic material that has the potential to improve environmental outcomes, making it a promising alternative to traditional cement materials [7]. Fly ash is an incidental product of the combustion of coal for energy generation. However, it is generally recognized as a pollutant to the environment. Fly ash, if left open in the field, can produce air, soil, and water pollution, which in turn results in the disruption of ecological cycles and environmental hazards. The fly ash, if not reused or decomposed, may have harmful effects on plants, human health, and on land because of traces of toxic metals [8]. From the ecological and environmental point of view, the disposal of fly ash is necessary and of great concern; hence, it is of utmost importance to dispose of it [9]. Consequently, disposal of the huge amount of this waste has become a serious environmental issue of concern, like other types of waste. For this reason, some have chosen to recycle the waste, while others have focused on re-use [10]. Another method of overcoming such challenges posed by waste is the utilization of these materials for engineering purposes in both construction and other industries, as reported by many researchers [11].

In the present scenario, eco-friendly materials are not sufficient to adopt, but better engineering outcomes like strength, workability, plasticity, tightness of water absorption, efflorescence, etc, are essential in the construction industry. In addition to providing an alternative suitable to improve engineering properties, fly-ash can be a welcome substitution to reduce the consumption of fertile soil for making building bricks. By including fly-ash in creating building blocks, the soil would be conserved against the sulphur content, which is found in fly-ash. Also, the concrete mixture ratio of fly ash in construction bricks can attain proper strength [12].

Recent studies showed that the concrete structures that are constructed in a corrosive environment have less service life, and their unexpected deterioration and/or expiry rate is too high. Therefore, to combat such problems, the construction of environmentally friendly concrete has gained importance nowadays. Recently, the usage of by-product materials, for instance, fly ash from industries, has lowered the consumption of Portland cement. The usage of fly ash to improve the strength of cement mortar has been studied by several researchers to check the incorporation of fly ash to improve the compressive and split tensile strengths of cement mortar

[13, 14, 15 & 16]. Moreover, fly ash is a substance with pozzolanic properties that can enhance strength development, providing an added advantage. According to Singh and Siddique [17], incorporating ash in cement mortar can boost resistance against sulphate and sulphuric acid attacks. Additionally, Torkittikul [18] notes that the porous structure of bottom ash can improve the thermal insulation characteristics of the mortar. However, Siddique [19] suggests that using ash may lead to reduced durability and resistance to abrasion and wear. However, the investigation on optimizing fly ash needs to be conducted. Therefore, the present study was conducted to optimize the fly-ash and cement ratio to construct cement blocks with reduced cement content by following national and international standards such as ES and ASTM.

## 2. Materials and Methods

### 2.1 Experimental site and materials used:

The experimental work was carried out in the laboratory of Farm Structures, Faculty of Agricultural Engineering, Sindh Agriculture University, Tandojam, to produce and evaluate fly-ash cement blocks (10×10×10 cm) by following the national and international standards. Ordinary Portland cement (OPC) was used in this study. Natural hill sand of the nominal size of 2 mm obtained from the Hyderabad market was used as fine aggregates for the preparation of the mortar mix. Fly ash was collected from Tradeworth International, located in Karachi. Table 1 shows the physical characteristics and chemical composition of the fly ash utilized in the production of mortar.

**Table 1: Chemical composition and physical properties of fly ash used in the study.**

Chemical composition		Physical properties	
SiO <sub>2</sub>	53.5%	Specific gravity	2.21
Al <sub>2</sub> O <sub>3</sub>	26.3%	Water absorption (%age by mass)	5.31
CaO	3.51%	Moisture content (%age by mass)	2.16
Fe <sub>2</sub> O <sub>3</sub>	9.65%	Density (Kg/m <sup>3</sup> )	685
MgO	0.81%	Fineness modulus	1.98
Na <sub>2</sub> O	0.17%		
K <sub>2</sub> O	0.61%		
P <sub>2</sub> O <sub>3</sub>	0.28%		
MnO	0.25%		
SO <sub>3</sub>	0.52%		

## ***2.2 Material Proportions***

Six treatments/mixtures comprising varying proportions of cement and fly-ash were evaluated. Mortar with 1:3 (cement: sand) was prepared, and the fly ash was used in place of cement. The substitution ratios of cement with fly-ash were 0, 10, 20, 30, 40, and 50% by volume. Five different mixtures of fly ash in cement blocks were used. The Ordinary Portland Cement (OPC) and hill sand, with a nominal maximum size of 4.76 mm, were used to manufacture control ( $T_1$ ). In mixtures T2, T3, T4, T5, and T6 of mortar, 10, 20, 30, 40, and 50% of cement was replaced with fly ash, respectively.

## ***2.3 Mixing, curing, and testing of mortar blocks***

Cement, sand, fly-ash, and water (water: cement = 0.4) were poured into the mortar machine for mixing in specified quantities and mixed for about 3 minutes at low speed. This ensured required adherence among the cement, sand, and fly-ash particles. Finally, the prepared mixture was placed in moulds as shown in Figure 1. The manufactured blocks were left in laboratory conditions for 24 h after being removed from the mould, and then cured with water for 7, 14, and 28 days (Figure 2).



**Figure 1: The appearance of a fresh mixture placed in moulds**



**Figure 2: The appearance of blocks just after moulding.**

After curing, the blocks were subjected to tests to determine compressive strengths, water absorption, and density as depicted in Figure 3. The compressive strength measurement shows the maximum amount of compressive stress that the block can withstand before collapsing. The compression test machine was used to determine the compressive strength of a 10×10 cm mortar cube by applying a maximum capacity of 2000 kN to the face of each sample.



**(a) Measuring Weight**



**(b) Taking Volume**



**(c) Water Absorption Test**



**(d) Compression Test**

**Figure 3: Measuring weight (a), volume (b), water absorption (c), and compressive strength (d) of mortar blocks**

To determine density and water absorption, the samples were dried in an oven at 110 °C till the mass did not change. The samples that had been dried were subsequently taken out of the oven and allowed to cool at room temperature, and the final weight was recorded. The blocks were then put in a water tank. In the tank, the blocks were removed after 24 hours. The blocks were then desiccated on the metal wire mesh to eliminate the excess water, and once again, the weight was recorded straight away to obtain the original/ saturated weight of the blocks. The water holding capacity per cm<sup>3</sup> of the matter was determined by finding the difference between the dry weight and fully saturated weight and dividing the resulting value by the total volume of the given sample. The density of the blocks was determined as the ratio of the dry weight of each sample to the total volume.

#### ***2.4 Statistical Analysis:***

To interpret the results, the data were subjected to statistical analysis using Statix 8.1 software. Analysis of variance was performed to determine the significant effect of curing time and fly-ash content on quality characteristics of the prepared blocks. Mean multiple comparisons were performed using the LSD test at 5% probability level.

### **3. Results and Discussion**

The usage of flay-ash in mortar to replace cement content without compromising the characteristics of mortar blocks was evaluated in terms of compressive strength, density, and water absorption. The results are discussed in subsequent paragraphs.

#### **4. Compressive strength**

Figure 4 shows that the research compared the compressive strength between fly-ash blocks that were manufactured using different proportions of fly-ash, as well as different curing durations. The results showed that the compressive strength of the blocks varied widely depending on the content of fly ash and the time of curing. Furthermore, Table 02 indicates that the effect of the interaction of the fly-ash and the curing time was found to be significant in determining the compressive strength of the blocks. As a rule, the percentage of fly ash added to the mixtures led to a reduction in the compressive strength. This might be explained by the weaker strength of the fly ash compared to cement mortar blocks, and more water is needed in the mixtures that involve fly ash. The compressive strength of the blocks, on the other hand, rose with the length of drying, with a rise in 7, 14, and 28 days of drying.

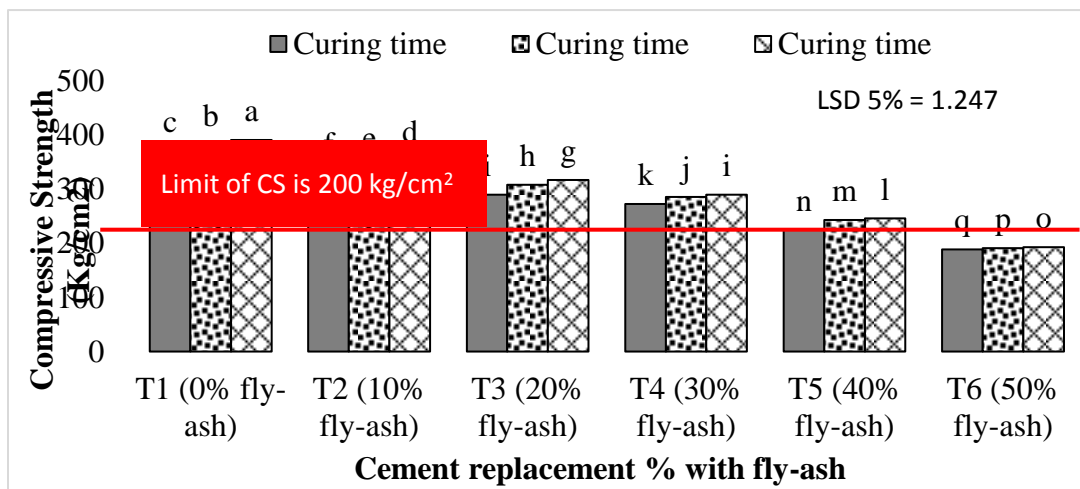
At 28 days of curing, the cement mortar blocks that contained 10% fly-ash had the highest compressive strength (338 kg/cm<sup>2</sup>), followed by those containing 20% fly-ash (297 kg/cm<sup>2</sup>), 30% fly-ash (281 kg/cm<sup>2</sup>), 40% fly-ash (233 kg/cm<sup>2</sup>), and 50% fly-ash (193 kg/cm<sup>2</sup>). The reduction of cement content from 15% to 10% also resulted in a decrease in compressive strength, as found by Alwash [20]. The compressive strength of cement blocks is directly influenced by cement content. Due to the slow reaction between fly ash and water, complete pozzolanic reactions typically take a longer period to occur. As a result, the strength of the mortar cubes increased significantly after 28 days. These findings are consistent with previous studies conducted by other researchers, which suggest that mortars containing fly-ash exhibit slower strength gain during the initial stages and delayed setting, resulting in extended curing time requirements [21 & 22]. Kim and Lee [23] utilized ash as a fine aggregate to produce high-strength lightweight concrete. However, studies such as Andrade et al. [24] have suggested that the addition of ash beyond a certain limit can lead to reduced strength development during the early stages. Singh and Siddique [25], through microstructural analysis, observed that the ash begins exhibiting pozzolanic activities after 28 days. Consequently, concrete that contains ash exhibits a higher rate of strength gain at a later age than control concrete, as noted by Aggarwal et al. [26].

Furthermore, cement mortar containing fly ash could be utilized in the production of load-bearing or non-load-bearing blocks. According to the guidelines set out in ASTM C 90-03 [27], the compressive strength limit for load-bearing cement blocks is 200 kg/cm<sup>2</sup>. To use fly ash optimally in the preparation of load-bearing cement mortar blocks, the amount of fly ash should be limited to 40% for load-bearing cement blocks. This is because the compressive strength falls within the permissible limit as long as the proportion of fly-ash does not exceed 40%, as shown in Figure 5.

**Table 2: Mean squares of compressive strength, water absorption, and density of cement mortar under the effect of fly-ash and curing time.**

SOV	Df	Compressive strength kg/cm <sup>2</sup>	Water absorption %	Density g/cm <sup>3</sup>
Replication	2	0.1	0.045	0.00002
Fly-ash (FA)	5	42589.5**	195.232**	0.67179**
Curing time (CT)	2	1622.0**	0.005 <sup>NS</sup>	0.00015 <sup>NS</sup>
FA × CT	10	55.4**	0.039**	0.00021**
Error	34	0.8	0.006	0.00006
Total	53			

\*\* = Highly significant at p<0.01 and NS = Non-significant



**Figure 4: Compressive strength (kg/cm2) of cement mortar blocks**

**5. Density:**

Figure 5 illustrates the influence of fly ash and curing time on the density of prepared cement blocks. The density values ranged from 1.69 to 2.41 g/cm<sup>3</sup>, with the control mixtures exhibiting the maximum density. The mean squares indicated that the utilization of fly ash had a significant impact on the density of manufactured blocks. However, there was no significant effect on density due to curing time and the interaction of curing time × fly-ash (Table 02). A linearly decreasing density of cement blocks was observed with increasing fly-ash content. At 28 days of curing, the cement mortar blocks containing 10% fly-ash had the highest density of 2.16g/cm<sup>3</sup>, followed by those containing 20% fly-ash (2.11g/cm<sup>3</sup>), 30% fly-ash (1.90g/cm<sup>3</sup>), 40% fly-ash (1.73g/cm<sup>3</sup>), and 50% fly-ash (1.70g/cm<sup>3</sup>). This reduction in density could be attributed to the

lighter weight of fly ash compared to cement. According to Nanda & Rout [22], the density of fly-ash concrete is 12.15% lower than that of control concrete. This makes it advantageous for constructing lightweight structures since the density of fly ash and bottom ash is considerably lower than that of natural fine aggregates. The density of normal solid cement blocks, as per guidelines of ASTM C 90-03 [27], is limited to 2.0 g/cm<sup>3</sup>. However, lightweight blocks offer several advantages over traditional cement blocks, such as reduced weight of the structure and better heat insulation.

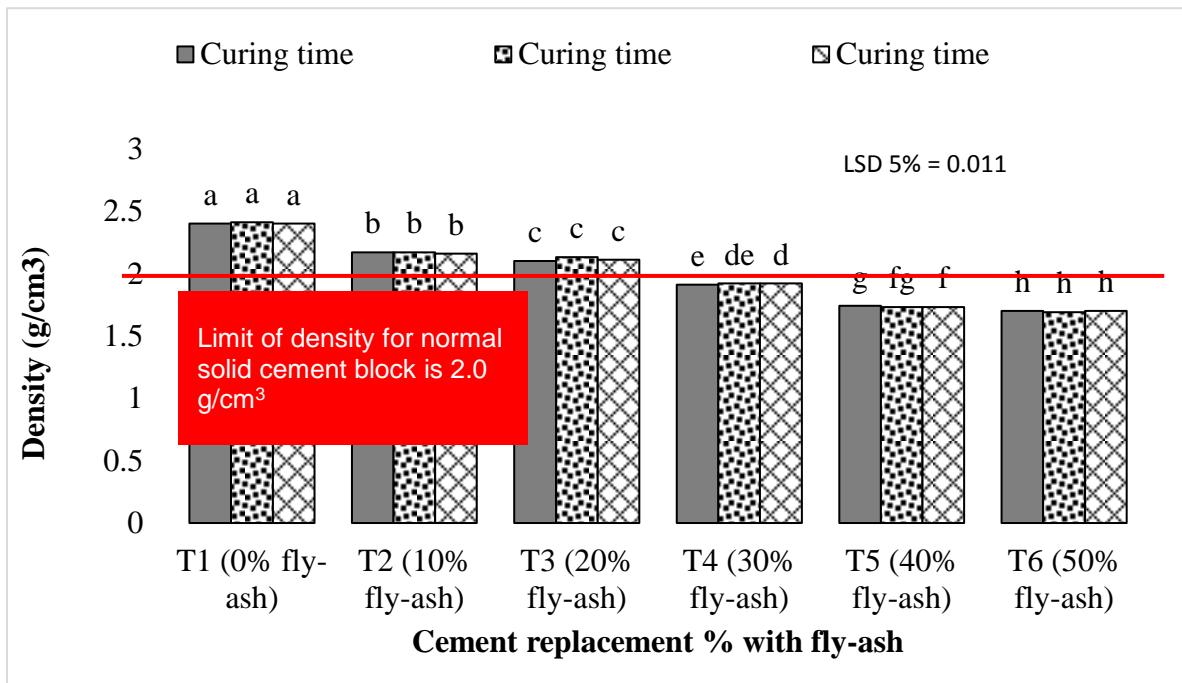


Figure 5: Density (g/cm<sup>3</sup>) of cement mortar blocks

## 6. Water absorption

The water absorption capacity of blocks has a significant effect on their durability. Since water can contain harmful ions and can also cause freeze-thaw damage to the blocks. Figure 6 indicates the water absorption values in percentage for the prepared cement blocks as influenced by fly-ash and curing time. Mean squares showed significant differences in water absorption of manufactured blocks due to the utilization of fly ash. However, curing time showed a non-significant effect on water absorption of the blocks (Table 02). It is noteworthy that the water absorption of the prepared blocks increases with increasing quantity of fly ash. Maximum water absorption was observed in cement blocks containing 50% fly-ash (22.2%), followed by 40% fly-ash (20.0%), 30% fly-ash (17.6%), 20% fly-ash (14.9%), and 10% fly-ash (12.1%) at 28 days

curing time. Fly ash increases the water absorption capacity of prepared blocks when it is used in the mixture as a binding material with cement, and due to its water-absorbent quality [12]. In their study, Nanda and Rout [22] found that the water absorption value and volume of pore space were higher in concrete containing the fly ash mixture when compared to the control. However, this type of concrete performed better in terms of resistance to sulphuric acid and sulphate attacks. According to ASTM C 90-03 [27], the maximum permissible limit of water absorption for normal solid cement blocks is 15%. The use of fly ash up to 40% increases the water absorption of cement blocks within the permissible limit. Therefore, cement mortar blocks produced in this study, up to 40% fly-ash, are considered an optimized quantity of fly ash.

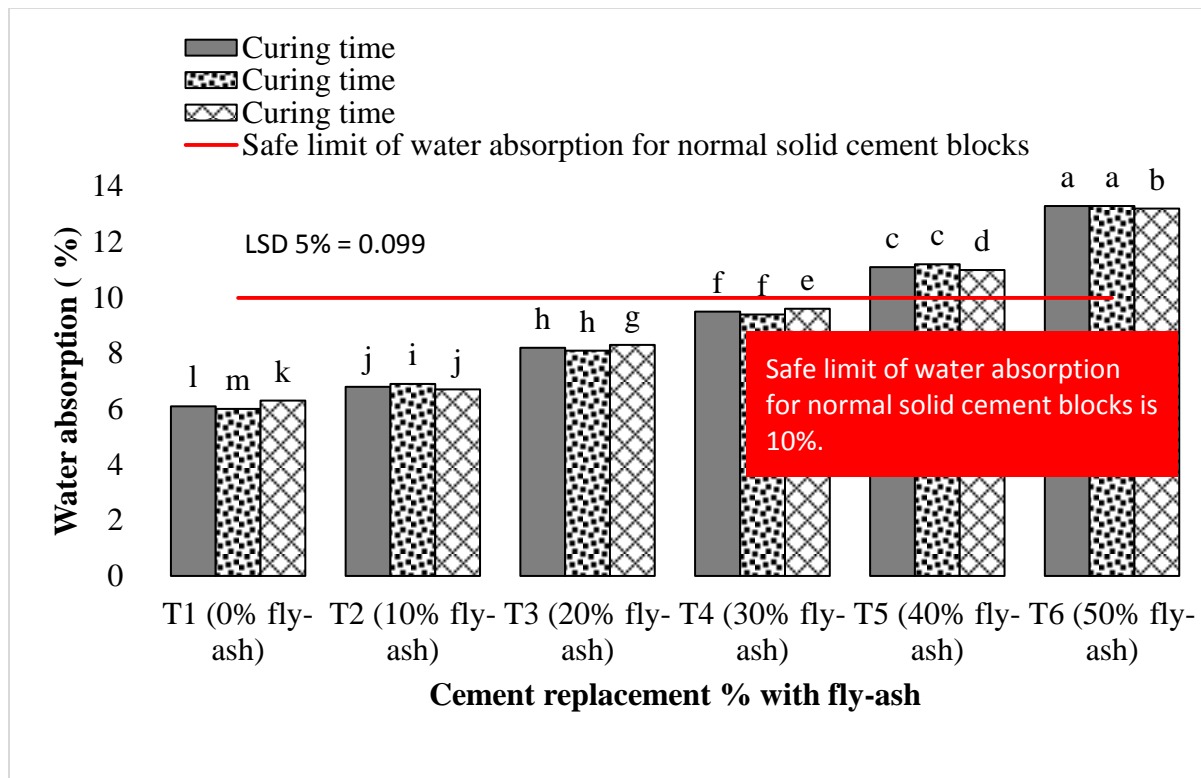
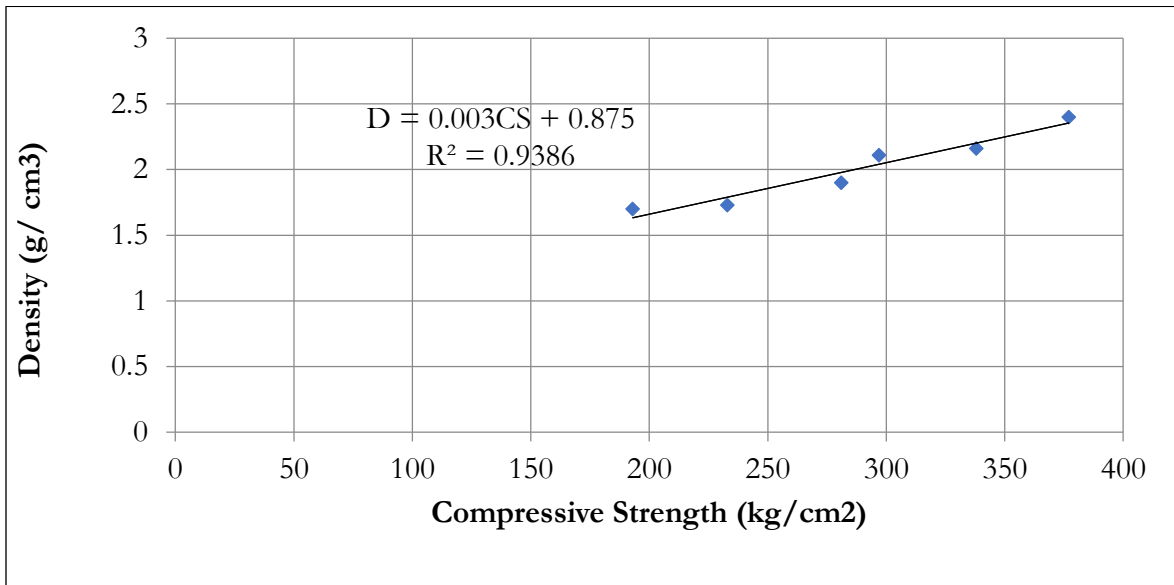


Figure 6: Water absorption % of cement mortar blocks

**6.1 The relationship between compressive strength and density of solid cement bricks**

Mechanical properties are directly affected by the density of the mortar unit, which implies that density is important in relation to mechanical performance. The relationship between the compressive strength and density of all mixtures, as demonstrated in Figure 07, gives the expression that is  $D = 0.003CS + 0.875$ . Where, CS is 28-day compressive strength in kg/cm<sup>2</sup>

and D is 28-day density in g/cm<sup>3</sup>. It is also evident that the compressive strength of cement mortar blocks is directly proportional to their density; the denser the block sample, the higher its compressive strength. The visualization of the results demonstrated that the outcomes achieved by the model are positively comparable to those of the observed outcomes. This correlation is applicable when the compressive strength of fly-ash blocks is assessed based on the density of the blocks.



**Figure 7: Correlation between the compressive strength and density for all mixtures**

## 7. Conclusions

The statistical analysis conducted in this study revealed a significant effect of the fly-ash content in cement mortar blocks on the compressive strength, water absorption, and density of the manufactured blocks. However, the curing time had a non-significant effect on the water absorption and density of the blocks. The results indicate that the compressive strength and density of manufactured blocks containing fly-ash decreased, and water absorption increased gradually by increasing the content of fly-ash. Nonetheless, using fly ash in the preparation of cement blocks meets the standards for both load-bearing and non-load-bearing units. When fly-ash is used in amounts up to 40%, it can increase the water absorption of cement blocks within the permissible limit of 15% and decrease the compressive strength below the safe limit of 200 kg/cm<sup>2</sup>. Therefore, for the optimal use of fly-ash in the preparation of cement mortar blocks, the amount of fly-ash should be limited to 40% for load-bearing cement blocks. However, additional

research is required to determine its durability under conditions of extreme exposure. The compressive strength of cement mortar blocks is proportional to their density; the higher the density, the higher the compressive strength. A relation between density and compressive strength was also developed to compute the compressive strength of fly ash-containing blocks.

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