# Evaluation of flexural strength in egg shell powder incorporated with fire clay using compressive strength – based empirical relations

**S. Perundevi[1], K. Ramesh[*] & G. Viruthagiri[2]**

[1] PG & Research Department of Physics, Government Arts College, B-Mutlur, Chidambaram, Tamil Nadu, India

[*] PG & Research Department of Physics, Government Arts College, B-Mutlur, Chidambaram, Tamil Nadu, India

[2] PG & Research Department of Physics, Thiru Kolanjiappar Government Arts College, Virudhachalam, Tamil Nadu, India

*Corresponding author: doctorkayar@gmail.com

**Abstract**

This study investigates the estimation of flexural strength of fire clay incorporated with egg shell powder using an empirical relations based on compressive strength and its correlated with porosity. The compressive strength of the samples is determined using the linear and square empirical relations. Porosity plays a significant role in influencing the clay mechanical properties of clay bricks, were higher porosity generally reduced strength. In this study the relationship between porosity, compressive strength and estimated flexural strength is analysed to understand the effect of eggshell incorporation on the mechanical performance of fire clay bricks. Experimental results indicated that compressive strength increased up to an optimum ESP content of 10% and decreased at higher replacement levels due to increased porosity and microstructural defects. Strength index values followed a similar trend, showing maximum performance at moderate ESP incorporation. Empirical models were developed to predict flexural strength using compressive strength and strength index parameters, while logarithmic regression analysis was employed to establish correlations with material ratio factor. The developed relationships demonstrated good agreement with experimental observations and showed that flexural strength prediction can be effectively achieved without direct testing. The study concludes that 10% ESP is the optimum replacement level for achieving balanced mechanical performance and sustainable brick production.

**Keyword**: Fire clay, Eggshell powder, Porosity, Compressive strength, Empirical relations, Strength Index, Material ratio factor.

## 1. Introduction

In recent years, the incorporation of agricultural and biological waste materials in construction materials has gained considerable attention. Egg shell waste is generated in large quantities from house holds food industries and porosity forms [3,4]. Egg shell mainly consist of calcium carbonate ($caco_3$), which can act as a filter or fluxing agent in clay products. The utilization of egg shell powder in fire clay not only reduces environmental waste but may also influence the physical and mechanical properties of the material [15,16] Mechanical properties such as compressive strength and flexural strength are important parameters in evaluating the performance of fire clay bricks. While compressive strength testing is commonly performed, flexural strength testing requires specialized equipment and is less frequently conducted. Therefore, empirical relationships are often used to estimate flexural strength from compressive strength values [23,17]

Egg shells mainly consist of calcium carbonates, which can influence the microstructure and porosity of fire clay bricks. Porosity is an important factor affecting the mechanical strength of the fire clay bricks an increase in porosity generally leads to decrease the compressive strength and flexural strength. In this study, the relation between porosity, compressive strength and estimated flexural strength is analysed to understand the effect of egg shell incorporate on the mechanical performance of fire clay bricks using the empirical relations

## 2. Materials and Methods

### 2.1 Materials

The primary material used in this study is natural clay, which serves as the base material for brick production. The clay was collected from a local source and processed to remove impurities such as stones and organic matter. The physical properties of clay play a significant role in determining the strength and durability of fired bricks [2].

Eggshell waste was collected from local food sources and cleaned thoroughly to remove adhering organic matter. The cleaned shells were dried and ground into fine powder. Due to its high calcium carbonate content, eggshell powder acts as a stabilizing and binding agent when mixed with clay [9,18]. The use of eggshell powder also contributes to waste recycling and environmental sustainability [8].

Water was added to the mixture to achieve the required plasticity for molding. Proper mixing ensures uniform distribution of eggshell powder within the clay matrix, which is essential for consistent strength development [5]


**Fig 1: Raw materials and preparation process of fire clay–ESP brick specimen**

### 2.2 Preparation of Brick Specimens

The clay and eggshell powder were mixed in different proportions, typically ranging from 0% to 20% by weight. The mixture was thoroughly blended to achieve homogeneity. Similar proportions have been used in previous studies to evaluate the effect of additives on brick properties [7].

After complete drying, the specimens were fired in a kiln at temperatures ranging from 900 °C to 1200 °C [18]. The firing process significantly enhances the mechanical strength of the bricks through sintering and the development of stable mineral phases. During this stage, particle bonding is intensified, resulting in a denser and more cohesive microstructure. The incorporation of eggshell powder further influences the firing characteristics by acting as a calcium-rich additive, which promotes improved inter-particle bonding and contributes to the overall structural performance of the fired brick [8].

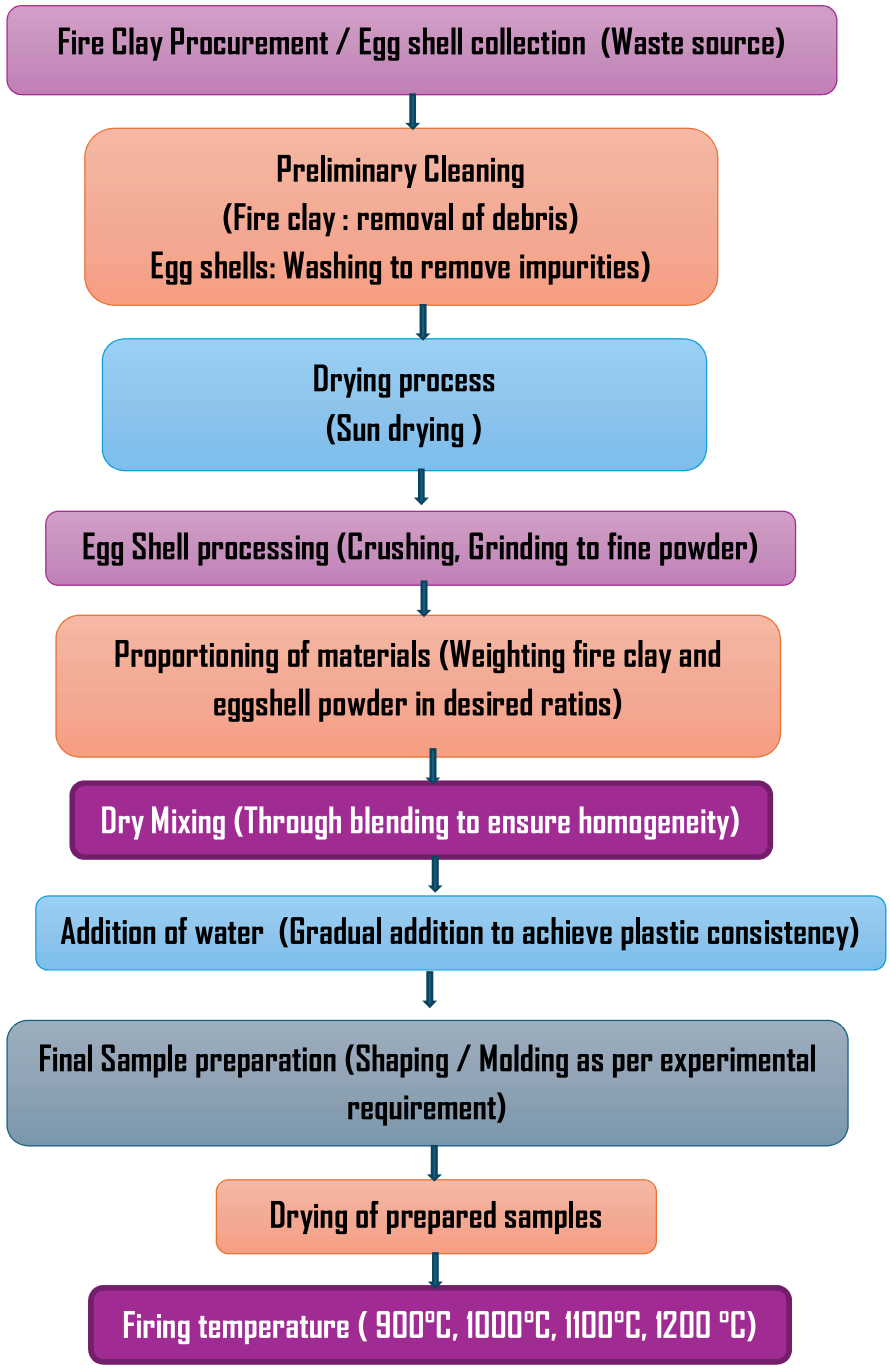



Fig. 2 Processing Flow Chart for Sample Preparation


**(a) Mechanical testing**


**(b) Fired brick specimens**

**Fig 3 Testing specimen**

**2.3. Significance of the methodology**

The methodology adopted in this study provides a practical approach for estimating flexural strength without extensive testing. It reduces time and cost while maintaining accuracy. The use of eggshell powder not only enhances material properties but also promotes sustainable construction practices. The empirical model developed in this study can be applied in real-world construction scenarios for quality assessment and design purposes.

**3. Parameters Studied**

**3.1. Compressive Strength Test**

The compressive strength of the fired bricks was determined using a compression testing machine. The test was conducted according to standard procedures, where load was applied gradually until failure occurred. Compressive strength is one of the most important parameters for evaluating brick performance [13].

The obtained values were recorded and used as the basis for developing the empirical relationship. Previous studies have shown that compressive strength is strongly influenced by material composition and firing conditions [4,6].

Its calculated by dividing the maximum load applied on the brick specimen by its cross sectional area [16,25].

$$f_c = \frac{P}{A} \quad (N/mm^2) \quad \text{-------------------------------} \quad (1)$$

Where $f_c$ - Compressive strength $(N/mm^2)$

P- Maximum load at break the specimen

A- Area of cross sectional of the specimen

**3.2. Flexural Strength Estimation from empirical relations**

Flexural strength is the maximum bending stress that a material can withstand before fracture under a flexural load.

The flexural strength values obtained theoretically were later compared with the values predicted using empirical relations. This comparison helps in validating the proposed model.

**Theoretical consideration**

Flexural strength estimation from an empirical relation. for many brittle materials like bricks (egg shell powder incorporated fire clay bricks) The square root empirical relation is

$$f_r = k \sqrt{f_c} \quad N/mm^2 \quad \text{----------------------------------} \quad (3)$$

here the empirical constant K= 0.15 to 0.7

A common adopted values in calculation is K = 0.60 (or) 0.65 [17,4].

Where

$f_r$ - Flexural strength $(N/mm^2)$

$f_c$ - Compressive strength $(N/mm^2)$

K - Empirical constant

The linear empirical relation is used to calculated the flexural strength $(N/mm^2)$

$$f_r = K.\ f_c \quad N/mm^2$$

The empirical constant K usually 0.08 – 0.12 for clay bricks with additives like egg shell powder

A commonly used approximation

$$f_r = K.\ f_c \quad N/mm^2$$

$$f_r = 0.1\ f_c \quad N/mm^2 \quad \text{----------------------------------} \quad (2)$$

Where

K - empirical constant

$f_c$ - Compressive strength $(N/mm^2)$

$f_r$ - Flexural strength $(N/mm^2)$

6

### 3.3. Apparent porosity

Apparent porosity is another important parameter that describes the volume of open pores present in a material relative to its total volume. It is a key factor influencing the durability, water absorption, and mechanical properties of fired clay bricks. Higher porosity generally indicates increased permeability, which may reduce strength but improve thermal insulation properties [19].

In this study, apparent porosity was determined using standard water absorption techniques, where the dry, saturated, and immersed weights of the brick specimens were measured. The presence of eggshell powder significantly affects the porosity of the bricks. During firing, the decomposition of calcium carbonate releases gases, which contribute to the formation of pores within the structure [8].

In the context of this study, analyzing apparent porosity is essential for understanding the internal structure of eggshell-modified bricks. It also helps in explaining variations in compressive and flexural strength. The results contribute to the development of a comprehensive understanding of how eggshell powder influences both physical and mechanical properties of fired clay bricks.

The porosity formula from water saturation method. It's the percentage oof void spare with a material [18,19].

$$\text{Apparent Porosity (\%)} = \frac{W_s - W_d}{W_s - W_{sub}} \text{ X } 100 \quad \text{-------------------------} \ (4)$$

Where $W_d$ – Dry weight of the brick specimen

$W_s$ - Saturated weight after soaking in water

$W_{sub}$ - Suspended weight in water

This relationship is widely used in material science and structural engineering [15,17]. Similar approaches have been applied in stabilized soil blocks and masonry units [14].

### 3.4. Logarithmic empirical index (LEI)

The logarithmic empirical index (LEI) was evaluated to understand the combined relationship between compressive strength and flexural strength of fired clay bricks incorporated with eggshell powder (ESP). The index was determined using the ratio between flexural strength and the natural logarithm of compressive strength, which provides a useful approach for assessing the mechanical efficiency of the developed brick specimens [21,22]. The expression used for the calculation is given below:

$$LEI = FS / \ln(CS) \qquad \text{------------------------------} \textbf{(5)}$$

where LEI is the logarithmic empirical relation FS represents the flexural strength and CS denotes the compressive strength of the brick samples.

### 3.5. Strength Index

The strength index (SI) of the fired clay brick specimens was determined to evaluate the combined influence of compressive strength and flexural strength on the overall mechanical performance of the developed bricks. The strength index was calculated using the following relationship [19,23]

$$SI = \sqrt{CS \times FS} \quad (N/mm^2) \qquad \text{--------------------} \ (6)$$

where:

- SI = Strength Index
- CS = Compressive strength ($N/mm^2$)
- FS = Flexural strength ($N/mm^2$)

### 3.6. Material Ratio Factor (k)

The Material Ratio Factor (k) was used to evaluate the relationship between flexural and compressive behaviour of the ceramic samples.

$$k = \frac{f_c}{f_r} \qquad \text{-------------------------------------------------------} \ (7)$$

It indicates the balance between compression and bending strength. A higher MRF shows brittle behaviour with low flexural capacity, while a lower MRF indicates better ductility and crack resistance. Material ratio factor K is important for evaluating material performance, optimizing mix design, and predicting structural behaviour.

### 4.0 Results and discussion

The mechanical and physical properties of fired clay-egg shell composited are summarized in the table.

**Table 1: Physical and mechanical properties of fire clay – ESP bricks samples at firing temperature (1000 °C) estimation of flexural strength**

| Egg shell powder (%) | Brick sample identifications | Temperature (°C) | Compressive strength ($N/mm^2$) | Apparent porosity (%) | Flexural strength ($N/mm^2$) | |
|---|---|---|---|---|---|---|
| | | | | | From Square root relation (if K=0.65) | From Linear relation (if K=0.12) |
| 0 | S0 | 1000 | 12.99 | 18.62 | 2.34 | 1.56 |
| 5 | S1 | | 14.92 | 14.92 | 2.51 | 1.79 |
| 10 | S2 | | 15.96 | 11.81 | 2.60 | 1.92 |
| 15 | S3 | | 9.93 | 18.90 | 2.05 | 1.19 |
| 20 | S4 | | 8.02 | 20.34 | 1.85 | 0.96 |

**Table 2: Physical and mechanical properties of fire clay – ESP bricks samples at firing temperature (1000 °C) of strength index, Logarithmic Empirical Index, and Material ratio factor**

| Egg shell powder (%) | Brick sample identifications | Temperature (°C) | Strength Index ($N/mm^2$) | | Logarithmic Empirical Index | Material ratio factor (k) | |
|---|---|---|---|---|---|---|---|
| | | | using square root relation | using linear relation | | using square root relation | using linear relation |
| 0 | S0 | 1000 | 5.5 | 4.50 | 0.91 | 5.6 | 8.33 |
| 5 | S1 | | 6.1 | 5.15 | 0.92 | 5.9 | 8.34 |
| 10 | S2 | | 6.4 | 5.44 | 0.93 | 6.1 | 8.31 |
| 15 | S3 | | 2.0 | 3.50 | 0.89 | 4.8 | 8.34 |
| 20 | S4 | | 3.8 | 2.91 | 0.88 | 4.3 | 8.35 |

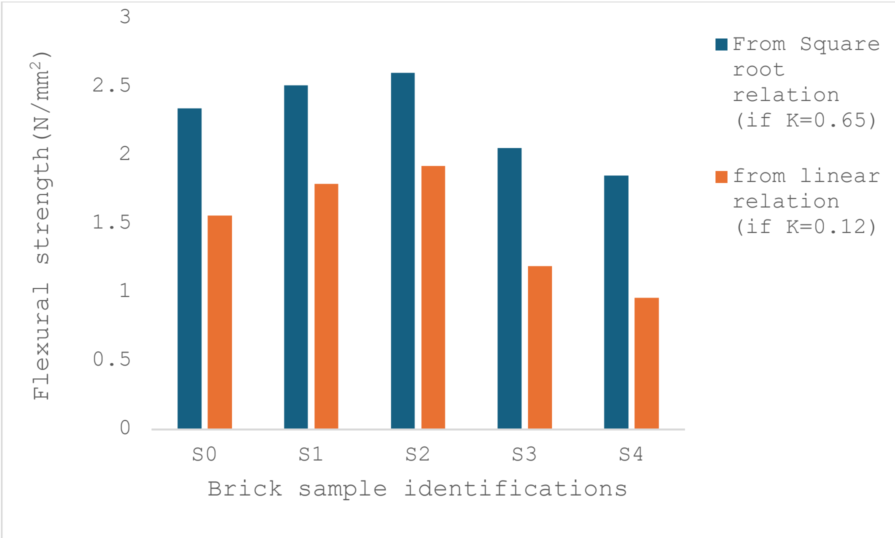



**Fig 4: The variations of flexural strength from square root and linear empirical relation with brick sample identifications**

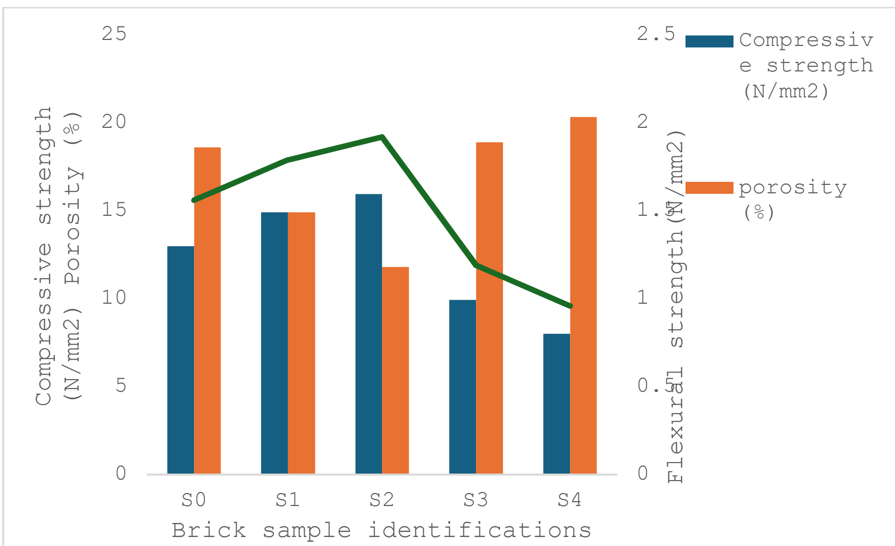



**Fig5: The compressive strength, porosity and flexural strength variations with brick sample identifications**

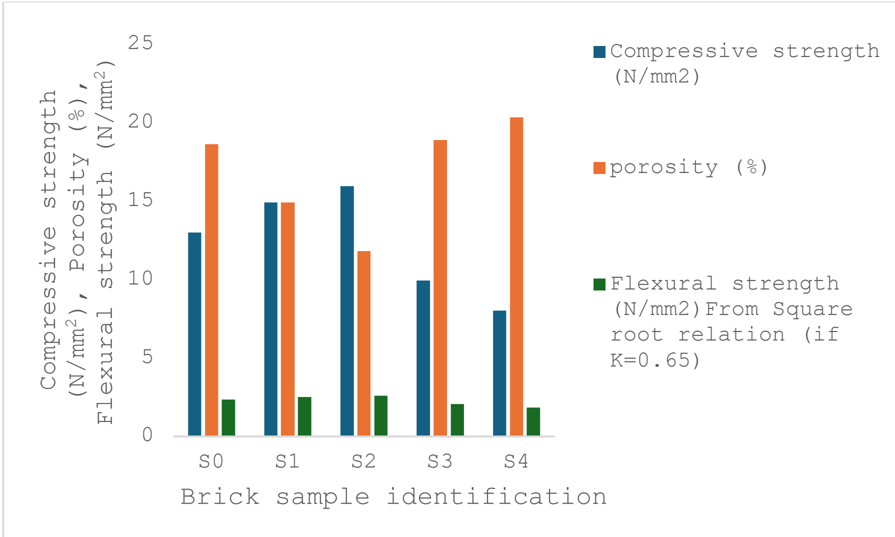



**Fig 6: The variations of flexural strength with porosity of the brick samples**

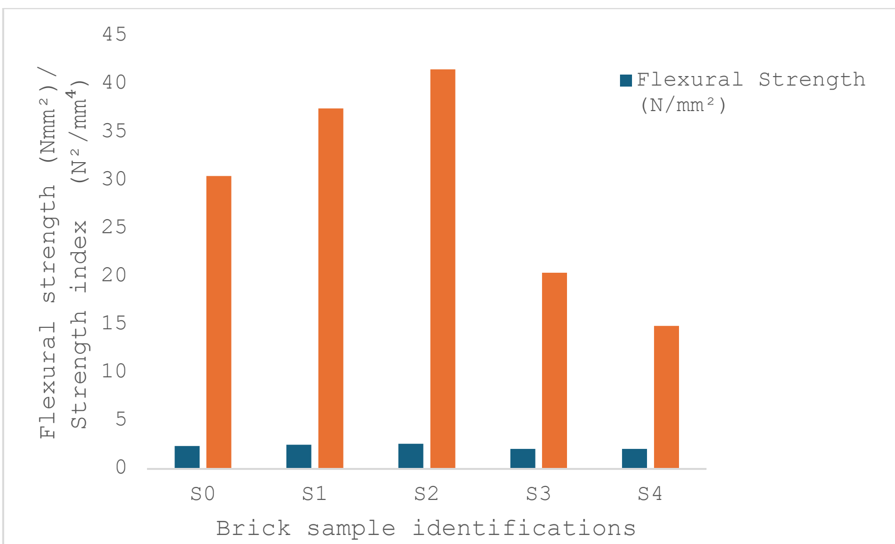
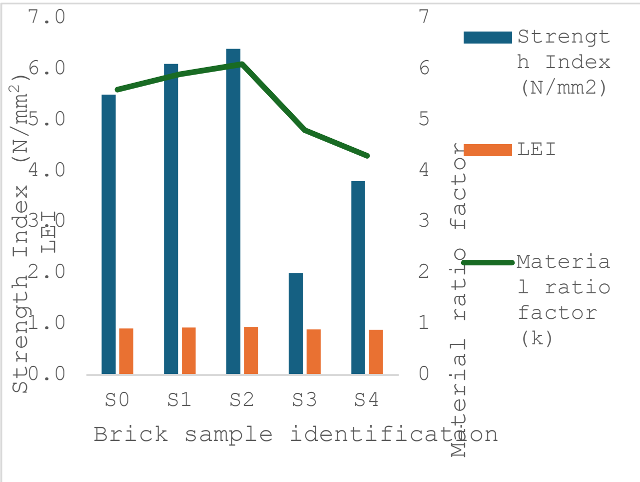



**Fig 7 : Flexural strength & strength index variation with brick sample identifications**



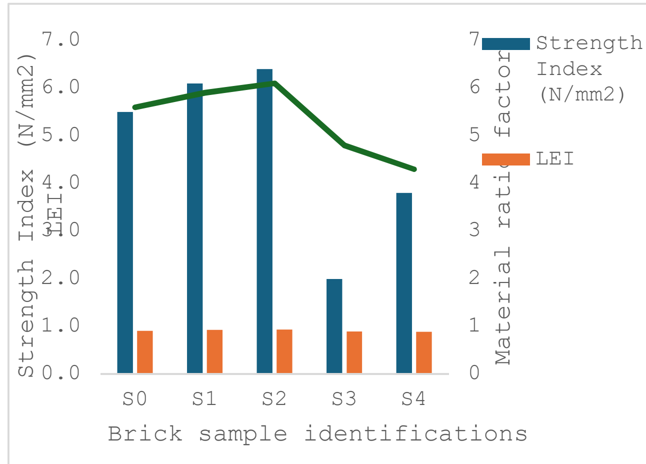




**Fig 8: Logarithmic Empirical Index, Material ratio factor & Strength index variation with brick sample identifications**

The physical and mechanical properties of fired clay bricks incorporated with eggshell powder (ESP) were evaluated at a firing temperature of 1000°C. The results obtained for density, compressive strength, apparent porosity, and estimated flexural strength are presented and discussed in this section. The estimation of flexural strength was carried out using both square root and linear empirical relationships. In general, the empirical constant k for clay-based materials lies between 0.08 and 0.12, and such relationships have been widely adopted for brittle materials [15,17].

The properties of fired clay incorporated with egg shell powder (ESP) showed a clear dependence on ESP content. Density increased to 10% then decreased to 1.69 g/cm$^3$ at 20% due to poor densification and incomplete positive bonding instead of forming a compact structure, the material retains a more porous and light weight frame work there by significantly reducing the density of the fire clay composite (Gas cannot escape uniforming because large pores and internal cracking are created) hence sharp loss in density and allow its strength. Porosity followed the opposite trend with a minimum of 11.81% at 10% ESP and maximum of 20.34 % at 20 %ESP. Compressive strength peaked at 15.96 N/mm$^2$ for 20%ESP, reflecting optimum packing and slight fluxing and dropped at lighter ESP content due to increased porosity and micro cracks [7].

Flexural strength, estimated using the square root (k=0.65) and linear (k=0.12) empirical relations, showed similar trends. Both methods indicated a maximum at 10%ESP (2.60 $N/mm^2$ and 1.92 $N/mm^2$ respectively) and decreased with higher ESP content [12]

The square root relation gave higher values, while the linear relation provided conservative estimates suitable for porous clay composites. For comparison with standard fire clay bricks typically exhibit flexural strength of 3-5 $N/mm^2$ . The estimated flexural strength using square root relation is 1.85 – 2.60 $N/mm^2$ indicating that K √compressive strength ($f_c$) may better capture the bending performance of fired clay composites. These for slightly below typical industrial ranges for standard fire clay bricks but can still be suitable for low-load applications or non-load bearing masonry [3].

The flexural strength was calculated using two empirical relations, and its values vary from 2.34 $N/mm^2$ to 1.85 $N/mm^2$ and 1.56 $N/mm^2$ to 0.96 $N/mm^2$. In both relations, the sample S2 exhibits the highest flexural strength. This indicates that S2 attains the maximum compressive strength.

At higher eggshell additions (15–20% ESP), the k values increased considerably. This increase suggests that compressive strength deteriorated more rapidly than flexural strength due to increased pore formation and reduced structural stability [22,23].

The higher material ratio factor (k =8.3) values observed at elevated eggshell contents indicate the development of a more brittle and weaker microstructure. These findings confirm that 10% eggshell powder is the optimum addition level for samples fired at 1000°C. Beyond this level, excessive eggshell incorporation negatively affects densification and overall mechanical integrity [24].

Although moderate eggshell addition improves material performance, excessive incorporation causes increased porosity and structural defects, resulting in deterioration of mechanical properties. The calculated Material Ratio Factor further confirms the change in mechanical behaviour with increasing eggshell content.

The variation of compressive strength flexural strength and porosity incorporated with fire clay bricks as shown in the figs. 5&6.

Porosity is the controlling factor decreasing porosity improves both compressive and flexural strength and all. these properties are strongly influenced by firing temperature and densification.

The calculated LEI values indicated a noticeable variation with the incorporation of eggshell powder. The control sample (S0) exhibited an LEI value of 0.91. With the addition of 5 wt.% ESP (S1), the index slightly increased to 0.92, suggesting an improvement in the interaction between compressive and flexural behaviour. A further increase was observed for the specimen containing 10 wt.% ESP (S2), which recorded the highest LEI value of 0.93. This improvement can be attributed to enhanced particle packing and better bonding within the ceramic matrix during firing, which contributed to improved mechanical integrity.

However, when the ESP content was increased beyond 10 wt.%, the LEI values showed a declining trend. The specimen containing 15 wt.% ESP (S3) produced an LEI value of 0.89, while the sample with 20 wt.% ESP (S4) exhibited the lowest value of 0.88. The reduction in the index at higher replacement levels may be associated with excessive pore formation and insufficient densification caused by the decomposition of calcium carbonate present in the eggshell powder during firing. These microstructural changes weakened the internal bonding of the bricks and consequently reduced both compressive and flexural strength.

Similarly, the results indicate that the strength index gradually increased with the incorporation of eggshell powder up to 10 wt.%. The control specimen (S0) exhibited a strength index value of 5.51 N/mm$^2$, while the addition of 5 wt.% ESP improved the value to 6.10 N/mm$^2$. The highest strength index of 6.33 N/mm$^2$ was obtained for sample S2 containing 10 wt.% eggshell powder. This improvement suggests that a moderate amount of eggshell powder enhanced the mechanical behaviour of the fired clay bricks by improving particle bonding and densification during the firing process.

Beyond 10 wt.% ESP incorporation, a noticeable reduction in the strength index was observed. Samples S3 and S4 showed lower values of 4.63 and 4.03 N/mm$^2$, respectively. The reduction in strength performance at higher ESP contents may be attributed to increased pore formation and insufficient vitrification caused by the decomposition of calcium carbonate present in the eggshell powder. These changes weakened the internal structure of the bricks and reduced their resistance to compressive and flexural loading.

**Conclusion**

The fired clay bricks incorporated with eggshell powder (ESP) showed satisfactory compressive strength, however, flexural strength decreased at higher ESP contents. The optimum performance was achieved at 10% ESP, which produced the maximum flexural strength and provided the best balance between mechanical performance and sustainability.

At higher ESP contents (15–20%), the reduction in flexural strength was attributed to increased porosity and microcrack formation, indicating the negative effect of excessive eggshell incorporation on the structural stability of the bricks.

The results obtained from the Logarithmic Empirical Index (LEI), Strength Index Parameter (SIP), and Material Ratio Factor (k) confirmed that 10% ESP is the optimum composition, providing improved bonding, better stress distribution, and enhanced mechanical behaviour. Overall, controlled incorporation of eggshell powder can be effectively used in fired clay brick production to promote sustainable material development while maintaining acceptable mechanical performance and durability. Beyond 10% ESP, mechanical properties and structural integrity gradually reduced.

**References**


1. Mevilia, A. M. (2011). Mechanical properties of fired clay bricks with waste additives. *Journal of Construction Materials, 5*(2), 45–52.
2. Hendry, A. W. (2011). *Structural masonry*. London: Macmillan Education Ltd.
3. Ajay, K., Sharma, R., & Singh, P. (2020). Effect of waste materials on mechanical properties of clay bricks. *Construction and Building Materials, 247*, 118125.
4. Srisuwan, A., & Phonphuak, N. (2020). Influence of waste additives on compressive strength of fired clay bricks. *Construction and Building Materials, 230*, 116923.
5. Kumar, S. (2003). Fly ash–lime–phosphogypsum bricks and hollow blocks for low-cost housing development. *Construction and Building Materials, 17*(5), 483–491.
6. Velasco, M., Martinez, G., & Lopez, J. (2020). Mechanical behavior of eco-friendly clay bricks incorporating waste materials. *Journal of Cleaner Production, 258*, 120130.
7. Thiaw, D., Wade, A. C., Sall, M., Diouf, S., & Dieye, G. (2026). Utilization of eggshells waste as an additive to improve the mechanical properties of clays. *Journal of Minerals and Materials Characterization and Engineering, 14*(2), 39–53.
8. Turgut, P., & Yesilata, B. (2019). Enhancing physical–thermal–mechanical properties of fired clay bricks by eggshell as bio-filler. *Science of Sintering, 44*(2), 207–220.
9. Amu, O. O., & Salami, B. A. (2010). Effect of eggshell powder on stabilization of clay soil. *Journal of Applied Sciences, 10*(21), 2784–2788.
10. Kumar, A., & Kumar, S. (2020). Eggshell powder as partial replacement in clay bricks. *Materials Today: Proceedings, 33*, 558–562.
11. Oluremi, J. R., Adedokun, S. I., & Osuolale, O. M. (2017). Strength properties of eggshell powder stabilized soil blocks. *International Journal of Engineering Research and Technology, 6*(8), 560–565.
12. Akinwumi, I. I. (2014). Soil modification using eggshell powder. *Journal of Engineering and Technology, 5*(1), 87–94.

13. Nnochiri, E. S., Ogundipe, O. M., & Ajao, A. M. (2017). Mechanical properties of stabilized earth blocks. *Construction and Building Materials, 148*, 652–659.
14. Onyelowe, K. C., Ezugwu, C. N., & Igboayaka, C. (2019). Correlation of compressive and flexural strength in stabilized soil blocks. *International Journal of Civil Engineering, 17*(4), 505–514.
15. Neville, A. M. (2011). *Properties of concrete* (5th ed.). London: Pearson Education.
16. Oluokun, F. A. (1991). Prediction of concrete tensile strength from compressive strength. *ACI Materials Journal, 88*(3), 302–309.
17. Rashad, A. M. (2013). Relation between compressive and flexural strength in cement composites. *Construction and Building Materials, 40*, 100–108.
18. Sutcu, M. (2015). Recycling of waste materials in the production of clay bricks. *Construction and Building Materials, 82*, 1–8.
19. Demir, S. (2008). Effects of organic residues addition on the technological properties of clay bricks. *Waste Management, 28*(3), 622–627.
20. Zhang, L. (2013). Production of bricks from waste materials: A review. *Construction and Building Materials, 47*, 643–655.
21. Tangboriboon, N., Moonsri, S., Netthip, A., Sangwan, W., & Sirivat, A. (2012). Enhancing physical–thermal–mechanical properties of fired clay bricks by eggshell as a bio-filler and flux. *Science of Sintering, 44*(2), 207–220.
22. Sutcu, M., & Akkurt, S. (2009). The use of recycled paper processing residues in making porous brick with reduced thermal conductivity. *Ceramics International, 35*(7), 2625–2631.
23. Monteiro, M. A., & Vieira, P. (2014). On the production of fired clay bricks from waste materials: A critical update. *Construction and Building Materials, 68*, 599–610.
24. Sutcu, M., Alptekin, H., Erdogmus, E., Er, Y., & Gencel, O. (2015). Characteristics of fired clay bricks with waste marble powder addition. *Construction and Building Materials, 82*, 1–8.
25. Danso, H. (2018). Properties of compressed earth bricks with agro-waste additives. *Journal of Materials in Civil Engineering, 30*(6), 04018088.