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ENHANCING MECHANICAL PROPERTIES OF CLAY BRICK BY USING STONE POWDER

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Abstract

Hundreds of studies have been written in the last several decades on the advantages of using stone powder as a raw material in the production of fired clay bricks. The durability and long-term behavior of the finished product, however, have received very little attention in the literature. Clay bricks are generally fired at high temperatures in developing countries, which reduces the mechanical performance of the bricks. This is especially evident in extreme environmental settings where weathering leads to significant damage. The evaluation of concrete waste (stone powder) used to make fired clay bricks is the main topic of this study. There are two sections: the first evaluates how adding stone powder to clay bricks improves their physical characteristics such absorption, efflorescence, density, and firing shrinkage. The impact of stone powder on the mechanical characteristics of specimens of burned clay bricks, such as compressive and flexural strengths, is covered in the second section. The percentages of stone powder in the clay bricks are 0 %, 5 %, 10 %, 15 %, and 20%. While the ratio of dry soil to water content remains is 0.3. In this work three fire phases are used untel to the maximum temperature is reached. The first one is 300 °C, the second phase is 600 °C, and 900 °C for the third phase. The water absorption of specimens decreased as the quantity of stone powder increased, and efflorescence also decreased, according to the results for the physical attributes. The density does, however, somewhat rise with the amount of stone powder. Additionally, when the amount of stone powder was increased, the experimental results indicated that firing shrinkage decreased. Mechanically considered, clay brick specimens with 20% more stone powder showed stronger compressive flexural capabilities.

Keywords:

Stone powder;
Clay bricks;
Efflorescence;
Compressive strength;
Flexural strength.

1 Introduction

The increase in Earth's temperature and the rising amounts of chemical pollutants like CO2 and CO (carbon monoxide) are the primary global goals for minimizing climate change. A system for controlling greenhouse gas emissions has been proposed by a few countries. The 15 member states of the European Community in 1997 have a shared reduction goal of 8% in CO2 emissions from 1990 for the years 2008 to 2012 [1]. To achieve strength, the bricks must be burned throughout the manufacturing process; they consume 24,000,000 tons of coal in one year. It is among the riskiest materials found in nature [2]. The bricks are burned at temperatures between 1000 °C and 1400 °C; consequently, in order to attain the required temperature, additional energy must be utilized [3, 4]. Since prehistoric times, burning clay bricks have been a popular building material, and they can still be found in many historic buildings at different levels of degradation [5]. The same role is still served by bricks today [6]. However, higher-quality fired brick is needed for modern construction. Due to the ceramic link formed when the silica and alumina components in clay mix, bricks have been developed to be stronger, more porous, and more uniform [7]. Due of the clay particles' strong binding and long-lasting nature, which are created during the burning of a wet clay brick [8], SiO2, or silicon dioxide, is an essential part of clay that melts when clay bricks are fired at a high temperature. The silicon dioxide creates a solid bond with the clay particles when it cools. There is a few studies [9] investigated the affected of straw fibers on compressive strength of unfired clay brick units. Another study that examines the effects of adding limestone powder on the mechanical and physical characteristics of burnt clay bricks is available [10]. There are several industrial wastes available nowadays, including fly ash, glass, and plastic. To recycle trash in order to lessen environmental pollution, as this is beneficial for both the environment and the economy. The idea that glass waste might be used as a possible fluxing agent to reduce the temperature of the clay bodies was presented by some researchers in previous studies. An alternate strategy to reduce production costs and energy usage would then be to recycle used glasses [11–17]. Additionally, it has been observed that using glass wastes in combination with specimens results in better density, less water absorption, and lower drying shrinkage [15, 16].

This study is particularly interested in exploring how adding stone powder to the clay mixture can enhance the physical and mechanical properties of fired clay bricks.

In this investigation, varying quantities of stone powder (0%, 5%, 10%, and 20%) were used in place of clay soil mixing, which was then wet using a compressor and placed in the molds with water. Every specimen was kept in room-temperature storage for 30 days. The molds were removed after the specimens had been prepared for a day. Every specimen was fired at three different temperatures: 300, 600, and 900 °C. Preheating is done at 300–600 °C, fire is done at 900 °C, and cooling is done at 0 °C.

2 Experimental work

The purpose of the experiment is to evaluate the effects of substituting different amounts of prepared stone powder for some of the raw clay in burned clay brick units. The results show that the specimens of fired clay bricks with various percentages of stone powder were compared with specimens made as a reference with no stone powder.

2.1 Dry clay soil

In this work, a layer of dry clay soil from Maysan city in southern Iraq was used, measuring around 1.5 meters (Ebttirah region). Fig. 1 depicts the procedure for collecting soil samples, finely granulating them, and sieving them through sieve # 8.

Fig. 1: Sample of dry clay soil.

2.2 Stone powder

Even though they are often disposed of in landfills, stone powder is produced annually from the waste of concrete or aggregates (coarse aggregate). Numerous literary works indicate that the addition of waste materials, such as waste marble powder [20] and cutting powder from granite and marble [18, 19], significantly improved the properties of clay bricks.

The initiatives on the incorporation of granite waste into clay-based products are, however, very limited [21]. Other studies are presented waste glass powder as replaced raw material (clay soil) in clay brick units. Additionally, even though recycling used glass to create new glass goods has many benefits for preserving natural raw materials, a significant amount of waste glass is disposed of in open landfills since it cannot be recovered due to impurities and the related costs of recycling [22]. The annual production of waste glass in the European Union (EU) is estimated to be 0.9 million tons [23]. This waste can contaminate the air and water because of its small weight [24]. Glass trash is one substance used in the production of ceramic items. When 10% waste glass was introduced to ceramic goods, improvements were observed in water absorption, apparent porosity, fire resistance, and apparent density [25]. This article presents the connection between the mechanical and physical properties of burnt clay bricks and the stone powder. In this investigation, clay soil is replaced with stone powder (Fig. 2).

Fig. 2: Sample of plastic powder (PS).

2.3 Water

The mixes for each specimen were made using tap water.

2.4 Brick manufacturing and brick mixing

For the laboratory examinations, five different mixes were made. Table 1 shows the characteristics of combinations. To compare the effects of five different percentages of stone powder (0%, 5%, 10%, 15%, and 20%), the combinations' water-to-soil (W/S) ratio was 0.3. The dry soil and stone powder content were combined for 2 to 3 minutes in a steel pan of the mixer. Water was added to the mixes while the mixer was operating to increase their homogeneity. Subsequently, the combinations were placed inside a 3 * 4 * 8.5 cm steel mold. To prevent the clay from adhering to the walls of the mold, grease was applied to the steel molds.

The steel mold was filled using the mix proportions shown in Table 1. In order to employ each percentage of stone powder in the physical and mechanical testing, ten clay brick samples were created. Figs. 3 and 4 demonstrate that steel molds and clay brick prototypes were created for each mixture. Using compression test equipment rated at 500 kN, air spaces in mixes were eliminated. Before the pressure load, the specimen had a thickness of 4 cm. After one minute of 15 N/mm^2 compressive load in a steel mold, all specimens had a thickness of 3 cm.

After that, the clay brick specimens were removed from the steel mold. While the mold was being demolded, there were no indications of deterioration in the clay brick. After one day, every specimen was received for the curing procedure. Subsequently, clay brick samples were allowed to air dry at 30-37 °C for a period of thirty days.

Afterwards, each specimen was fired three times in a furnace that could reach a maximum temperature of 1200 °C, at combined temperatures of 300, 600, and 900 °C. Three stages comprise the firing: the first preheats at 300 to 600 °C for 65 minutes, the second fires at 900 °C for 30 minutes, and the third cools for 60 minutes. ASTM C62-03 requirements were followed in the production of the fired clay specimen. See Fig. 5.

Table1: Quantities for all percentages of stone powder in mixtures.

ID Specimens	W/S	Stone powder %	Stone powder [kg/m^3]	Soil [kg/m^3]
Stone powder 0 %	0.3	0	0	2600
Stone powder 5 %	0.3	5	130	2470
Stone powder 10 %	0.3	10	260	2340
Stone powder 15 %	0.3	15	390	2210
Stone powder 20 %	0.3	20	520	2080

Fig. 3: Clay brick (green clay brick) specimens with molds.

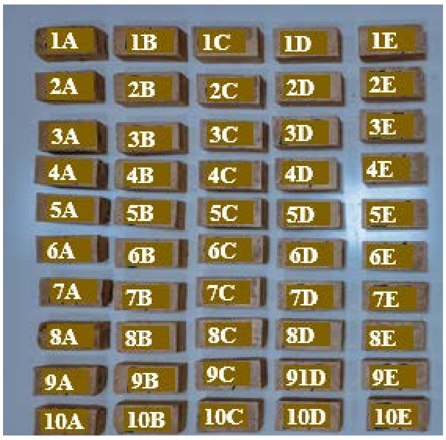

Fig. 4: Specimens of fired clay brick for all mixes of stone powder.

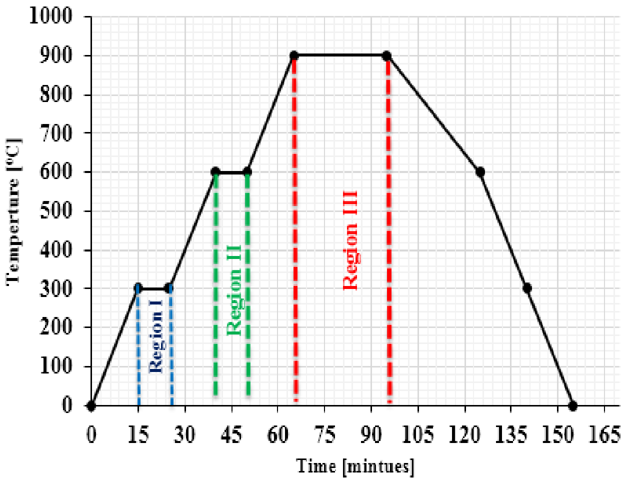

Fig. 5: Time-temperture relation for fired clay brick specimens for all mixes of stone powder.

3 Results and discussion

According to experimental findings, stone powder significantly affects the mechanical and physical properties of burnt clay bricks, including their compressive and flexural strengths, density, absorption, efflorescence, and firing shrinkage. The particular qualities are discussed in more detail below.

3.1 Water absorption

The water absorption capacity of clay bricks is a major factor in determining their durability. Demir says that a brick loses some of its durability when it leaks. Therefore, the internal structure of a burned clay brick needs to be sufficiently dense to keep out water. High temperatures and a high quantity of stone powder were utilized to create clay bricks with a high density and reduced water absorption; for instance, reference specimens' water absorption was reported to be 24%; specimens with 20% stone powder had a 20% decrease in this illustration.

During the fire process, the clay particles will typically pack closely, changing the crystalline makeup of the brick and raising its density. This work provides three fire temperature areas: 300 °C for ten minutes, 600 °C for ten minutes, and 900 °C for thirty minutes. The stone particles melted in the powdered stone samples when they were heated to high temperatures, increasing the density of the clay bricks. The authors have noted a decrease in water absorption with high stone powder. It also means that most stone powder melts at a high temperature during fire, creating filled gaps inside the brick structures. Blasius Ngayakamo et al. found that the inter-particle cohesiveness induced by the melting of sintering agents was the reason for the low apparent porosity values in clay bricks with 10, 20, and 30% weight percentages of additional granite powder, which reduced the quantity of macro- and micropores in the clay brick matrix. According to Iraqi Specifications, Table 2 shows the upper and lower bounds for clay bricks' water absorption rates (IQS 25-1988).

Fig. 6 refers to the relationship between absorption and stone powder. It is evident that the clay brick specimens without stone powder had a higher water absorption rate of 24%, or Type C. On the other hand, specimens containing 20% stone powder exhibited a 20% water absorption rate, indicating Type A.

It was found that, generally speaking, water absorption decreased as the clay brick specimens' percentage of stone powder increased. In other words, the lower the stone powder's water absorption, the greater the amount of stone powder created. Fig. 6 is an example.

Table 2: Iraqi Specifications set maximum water absorption percentage limitations for clay bricks (IQS 25-1988).

Class of Clay Brick	**Maximum limits of water absorption [%]**	
	One unit	**Average of 10 units**
A	22	20
B	26	24
C	28	26

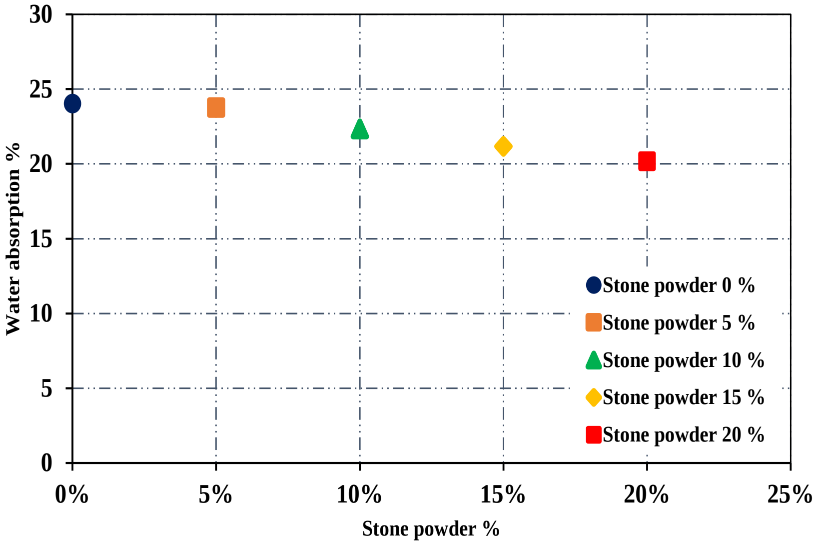

Fig. 6: Water absorption-Stone powder relationship.

3.2 Efflorescence of clay brick

Salt efflorescence is the term used to describe the formation of salt crystals on a surface as a result of water evaporating from the slats, and it is a prevalent surface issue on clay brick, mortar, and concrete facades. It usually involves white, soluble salt deposits, such as sodium chloride or alkali sulfates, that normally show up shortly after the facade is constructed.

The area is impacted by efflorescence in clay brick specimens that contain stone powder. It was discovered that the use of stone powder reduced efflorescence. For example, efflorescence was observed on only 16% of the reference specimens' surface area (i.e., 0% of the stone powder), whereas it was present on 12.7% of the clay bricks containing 10% of the stone powder. For the specimens containing 5% stone powder, the efflorescence was 15.6%. Furthermore, this interaction is shown in a positive light. According to ASTM C67-03 requirements, this test was conducted, and the results indicated that the addition of stone powder reduced the efflorescence area, see Fig. 7. At temperatures higher than 1100 °C, stone powder melts and connects the pores, minimizing the absorption of water. The materials' porosity is affected by it. Conversely, a reduction in porosity led to less water absorption and the least amount of efflorescence.

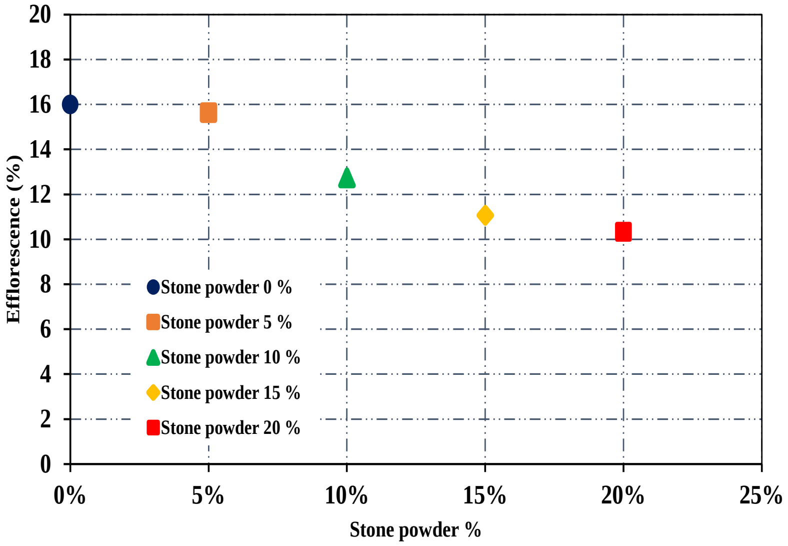

Fig. 7: Efflorescence- Plastic/Glass relationship.

3.3 Clay brick density

The association between specimen densities and percentages of stone powder is illustrated in Fig. 8 (see below). The density of the sample was calculated by dividing the mass of the specimen by its calculated volume. The specific gravity of the raw material, the production process, and the level of burning all affect the density of clay brick. The results show a slight rise in density with increasing stone powder content. For example, replacing the clay with 5% stone powder produced 3% fewer specimens than replacing it with 10% stone powder. The densities on the opposite ward are observed to have increased by 3%, 5%, 7%, and 10%, respectively, with the values of stone powder being 5%, 10%, 15%, and 20%. A temperature of 1100 °C or more causes the stone powder to melt and fill the gaps in the clay structure, increasing the density of bricks. For example, specimens containing 20% stone powder have a few voids, which influence the weight of the specimen. Previous studies found that bricks with a greater bulk density are produced when clay and granite powder are combined. The increase in waste concrete powder in fired brick clay led to an increase in bulk density.

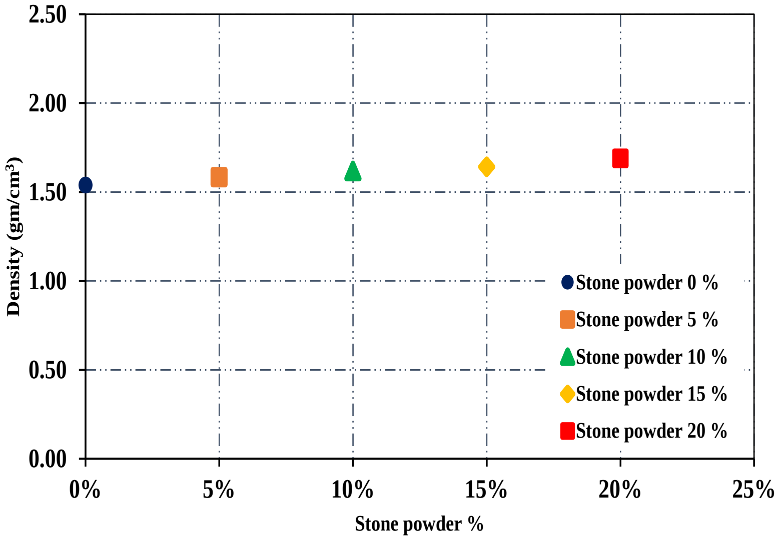

Fig. 8: Density- Stone powder relationship.

3.4 Firing shrinkage

In accordance with ASTM C326-03, a linear shrinkage was measured with a caliper that had +0.01 mm accuracy to measure the brick sample's volume both before and after the fire. Clay particles compact closer together as a result of the water that evaporates between them, which leads to shrinkage, which is one of the contributing factors to fire shrinkage.

Fig. 9 shows the relationship between shrinkage and the quantity of stone powder in all groups of specimens after the fire. The graph's points each show the variation range and the average of the shrinkage values for the three specimens.

Nevertheless, a steady drop in firing intensity was evident in the data. The results clearly showed that the shrinkage caused by fire was between 5% and 1.5% for stone powder concentrations of 0% and 20%, respectively. However, the shrinkage decreased in proportion to the rise in stone powder quantity.

Additionally, shrinkage was seen to decrease with an increase in the percentage of stone powder in clay brick specimens. However, the melting of the compaction agents created inter-particle cohesiveness, which in turn reduced the amount of macro-and micropores in the clay brick specimens, which is why the apparent porosity values in clay bricks with 5%, 10%, 15%, and 20% of stone powder added were low. In comparison to other clay bricks, the shrinkage values for the clay bricks containing 15 and 20 percent stone powder were the lowest.

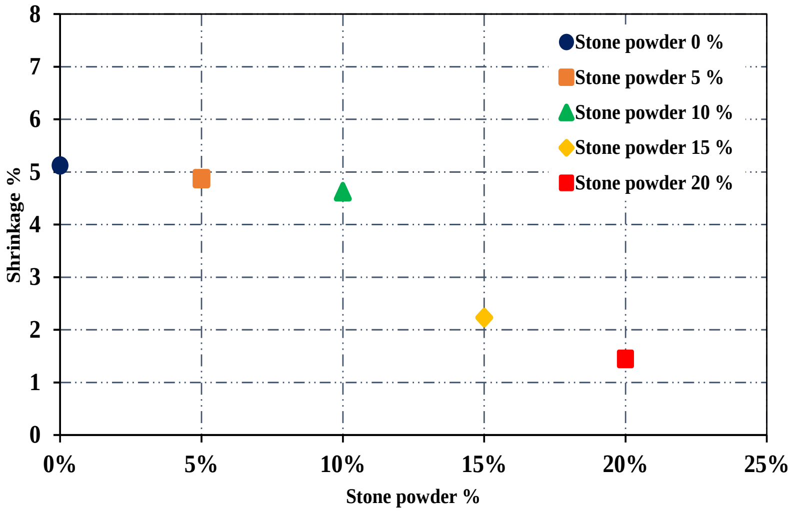

Fig. 9: Shrinkage- Stone powder relationship.

3.5 Compressive strength

Bricks are mostly compressed when used to construct different kinds of structures. As per the ASTM C67-03 standards, the values of compressive strength derived from the test specimens are presented in Fig. 10. With the addition of stone powder, it was found that the mechanical strength data of clay bricks improved as a result of vitrification, densification, and the creation of the multi-phase. High compressive strength was also influenced by a decrease in porosity and an increase in bulk density brought on by the clay bricks' inter-particle cohesion. The microstructural consolidation that was aided by the melting of the fluxing agents improved and increased the clay bricks' compressive strength values. The reference specimens (i.e., without stone powder) attained a 9.3 MPa compressive strength; in contrast, specimens that included stone powder showed higher values in the 9.9–11.1 MPa range. On the other hand, as shown in Fig. 10, the compressive strength increases with increasing levels of clay substitution by stone powder. The average compressive strength values are strongly correlated with the amount of stone powder, meaning that the amount of stone powder significantly increases the compressive strength.

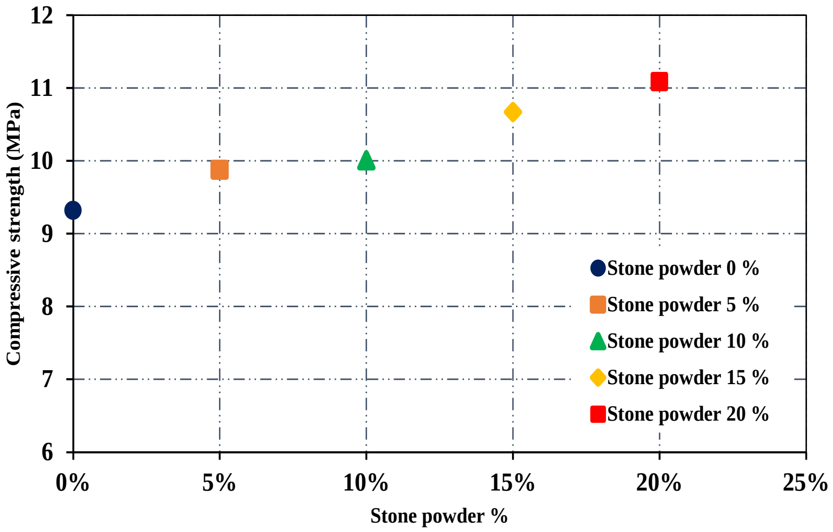

Fig. 10: Compressive strength- Stone powder relationship.

3.6 Flexural strength

The flexural test was conducted in compliance with ASTM C67-03, as demonstrated by the flexural strength test results for all stone powder levels displayed in Fig. 11. Each of the flexural strength results shown in Fig. 11 is the mean of three brick specimens. It was discovered that when the stone powder content was 20%, the flexural strength was greater. In contrast, the reference specimens demonstrated a minimum flexural strength value with a lower amount of stone powder—that is, zero stone powder. The percentage of stone powder increases with a constant growth in flexural strength. 15% more for specimens with 5% stone powder and 100% more for those with 20% stone powder.

In general, the experiment's findings showed that brick specimens' flexural strength increased in proportion to the quantity of stone powder they contained. As the number of voids reduces, brick specimens' flexural strength will rise. Stone powder enhanced the flexural strength of bricks by reducing porosity.

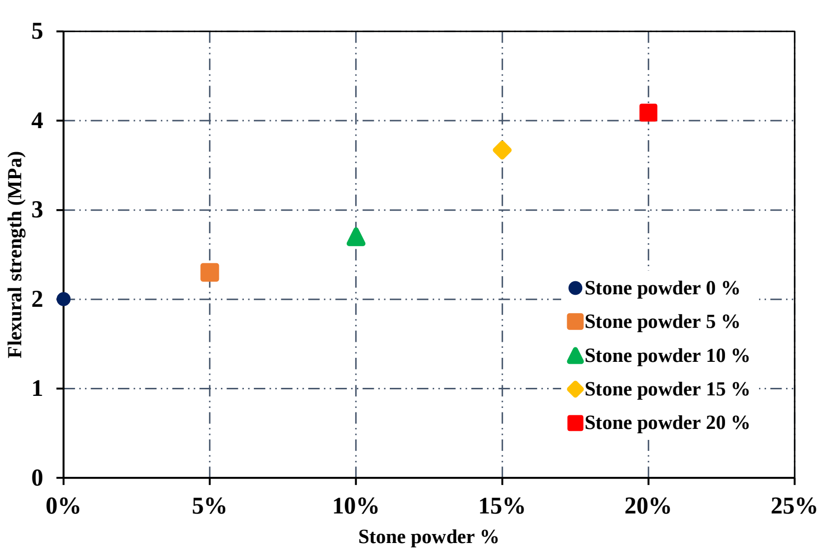

Fig. 11: Flexural Strength- Stone powder relationship.

4 Conclusions

The testing results on burnt clay brick materials made by replacing clay raw materials with stone powder brought to light the following points:

1) Clay brick specimens' water absorption can be gradually increased by replacing a sufficient amount of clay with stone powder during the firing process. When stone powder is used to partially replace clay in the range of 5–20% by weight of clay, water absorption is decreased by 24–20.2%.

2) The efflorescence of clay brick specimens dropped when stone powder was used in place of clay; that is, because stone powder is between 0% and 20% by weight of clay, the efflorescence value dropped from 16% to 10%. Nonetheless, the efflorescence diminishes with increasing stone powder content.

3) It was found that adding stone powder increased the density of burnt clay brick examples. A stone powder has a range of 0 to 20% when its density is between 1.5 and 1.7 g/cm^3.

4) There is less firing shrinkage in clay brick specimens that have 20% stone powder added. However, the findings indicated that using stone powder reduced firing shrinkage.

5) The specimens with 20 percent stone powder had a higher compressive strength (11.1 MPa) compared to the reference specimens' 9.3 MPa.

6) The addition of stone powder to specimens enhanced their flexural strength; that is, specimens with 5% stone powder had a 15% increase in flexural strength, whereas specimens with 20% stone powder had a 100% increase.

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