

# Effects of Firing Time and Temperature on Physical Properties of Fired Clay Bricks

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**Abstract:** Brick is one of the most widely used conventional construction materials throughout the world. The production cost of clay brick is significantly affected by the cost of energy required for firing. The aim of this research is to investigate the effects of different firing temperatures on the compressive strength (CS), water absorption (WA) and saturation coefficients (SC) of fired clay bricks produced around Jimma Town and evaluate the effect of firing processes in brick manufacturing on the properties, color and appearance of the clay brick. During the production process, the effects of different heating rates on physical and mechanical properties of firing standard bricks were analyzed. In this study, different heating rates were used: slow heating rate and fast heating rate. Changes in the physical and mechanical properties of the fired clay brick were assessed with the increase in the firing temperature firing time. The results show that the CS increased with the increase in the firing temperature. On the contrary, WA and SC of the fired clay bricks decreased with the increase in the firing temperature. Increment in the duration of firing slightly increases the CS and lowers both the WA and WA of the clay brick. In the study area, traditional brick producers did not have firing temperature control device or mechanism in the fired clay brick production. The kiln operator decided the firing temperature and duration. The absence of the device frequently results in the over or under firing of bricks greatly affecting the engineering properties of this widely used contraction material. Therefore, the traditional clay brick producers should install the temperature control device on their kiln or at least needs to be trained how to approximately determine the optimum temperature.

**Keywords:** Burnt Clay Brick, CS, Firing Temperature, Saturation Coefficient, Water Absorption

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## 1. Introduction

Bricks are more commonly used in the construction of buildings than any other material, with the exception of wood. Brick and terracotta architecture is dominant within its field and various industries have been developed and invested in the manufacturing of different types of bricks of all shapes and colors. With the advancement of modern machinery, earth moving equipment, powerful electric motors and modern tunnel kilns, making bricks has become far more productive and efficient than ever before [1, 4, 5]. Bricks can be made from a variety of materials the most common being clay, but also calcium silicate and concrete are raw materials for brick production. With clay bricks being the most popular, they are

now manufactured using three processes: soft mud, dry press and extruded processing [1, 4, 5, 7].

In the modern brick production fuel oil is used and covers less than 2% of the total annual brick production [2, 12]. The annual clay bricks production in Ethiopia is not more than 30 million pieces. This quantity is very small when compared to the amount produced in other countries. Clay bricks are transported hundreds of kilometers from the factories to regional cities in Ethiopia. Traditional clay bricks are widely produced in Jimma and Hollata, Oromia Regional National State, Ethiopia. According to [4, 11, 14, 15], construction materials for wall and distribution of households by construction material have not been well studied and compiled in a data base in the country. However, the report shows that about 76.0% of the country's total households reside in dwelling units with walls constructed

from wood and mud. These types of houses are more common among urban households (82.4%) than rural (74.8%). Slightly more than 9% of rural and 1% of urban households dwell in wood and thatch houses. Households living in housing units with walls constructed of stone and mud constitute 9.1% in rural and 6.3% in urban areas. Dwelling units with wall constructed by other types of materials are uncommon (< 10%) in both the urban and the rural areas. According to this analytical report, in Ethiopia, only 0.1% used bricks as a walling material. This indicates that the use of clay bricks in the Ethiopian construction industry as a walling material is low. Some of the main reasons are their higher costs when compared with hollow concrete blocks, limited amount and shapes of production. Therefore, scientific in puts supported by researches for the development of the clay brick industry is vital [11-12].

Most of the traditional clay brick production system in and around Jimma is obsolete and produce limited type and amount of clay bricks when compared with other countries [1]. Furthermore, over and under fire clay bricks production is the regular practice of these traditional factories. One of the major contributing factors for this problem is poor kiln firing temperature controlling mechanism. So, besides assessing the kiln firing temperature controlling mechanism of traditional clay bricks production systems, determination of the effect of firing temperature on the compressive strength (CS), water absorption (WA) and saturation coefficient (SC) of clay bricks could be vital input in improving the quality of traditionally produced clay bricks throughout the country.

## 2. Sample Collection and Data Analysis

### 2.1. Location of Clay Soil Sampling Sites

Samples of clay soil were collected from two localities Marawa (Bada Buna) and Bore (Askola) around Jimma Town (Fig. 1). These clay soil samples were investigate at Jimma University laboratory.

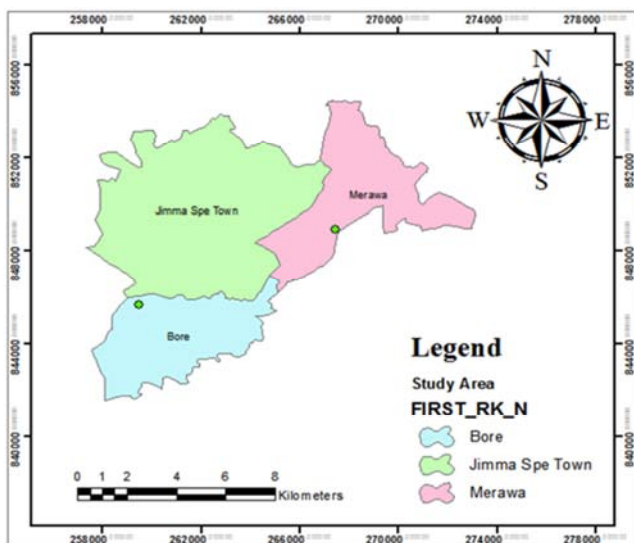


Fig. 1. Point locations of sampling sites.

### 2.2. Preparation of the Raw Materials

The procedures employed in this study for the production of clay bricks include preparation of the raw materials, mixing, shaping, drying and firing of bricks. The procedures of clay soil sample collection and methods of preparation of the bricks for firing is shown in Fig. 2. The index properties of the soil samples from the two localities are given in Table 1.



Fig. 2. Photo taken during the collection of soil sample (February 2016).

The red clay soil from Bada Buna and the greyish clay soil from Bada Buna were transported to the production site. The production site for this study is in Jimma Town. The samples were dried in an open air. The oversized soil particles are manually crushed and sieved again and again before molding to produce bricks for firing.

#### 2.2.1. Forming

For the production of clay bricks from the two soil samples, each sample was mixed with water and the amount of water used for mixing is based on the plastic and liquid limit of the soil samples. Mixing of the soil sample with water was done manually. Shaping of the mixed soils at their plastic state was done using a wood mould of size 25 cm x 12 cm x 6 cm for the clay soil from Bada Buna, while a mould size 25 cm x 12 cm x 6 cm was used for the sample from Askola site. Since the furnace available in the laboratory for firing the bricks is very small, such small size mould is selected. Moreover, wood ash is used to lubricate the formwork so that it prevents the plastic raw material mix from sticking on the formwork. All the shaping activities were done manually. During shaping the plastic clay was compacted manually to reduce the void in the mix.

#### 2.2.2. Drying

The green bricks were kept in a room for four days, then placed in a shed to be dried with air for six days. The time of

drying is dependent on the moisture content of the green bricks and the humidity of the production area.

### 2.2.3. Firing

Firing of the dried brick at temperature 700, 970 and 1200°C was done using furnace (Fig. 3) at Mechanical Engineering Department Testing Laboratory, Jimma Institute of Technology. The clay bricks were fired separately at different firing duration keeping the temperature constant.



Fig. 3. Firing brick samples in a furnace.

Moreover, the bricks produced from the two sites are fired for 2, 4, 6 and 8 h separately at a constant temperature of 970°C to test the effects of duration of firing temperature on

the physical and mechanical properties of these bricks.

### 2.2.4. Laboratory Tests of the Fired Clay Bricks

CS, WA and SC of the fired clay bricks separately produced from the two sites were tested in the Construction Materials Testing Laboratory at Jimma Institute of Technology, according to the Ethiopian Standard Specification for Solid Clay Bricks. The test results are analyzed based on the Ethiopian standard specification of solid clay bricks [3, 8].

Table 1. Physical properties of sampled soils.

Soil sample	LL	PL	PI	Specific gravity (g/cm <sup>3</sup> )	Water used for mixing (% by weight)
Beda Buna	38	28	10	2.5	30
Askola	62	40	22	2.48	47

### 2.3. Data Analysis and Presentation

The numerical values of the mechanical properties of the fired clay bricks were the mean of five bricks produced using each of the soil samples collected from Bada Buna and Askola. The analyzed data are presented using table and figure.

## 3. Results and Discussions

### Properties of the fired Clay Bricks

The experimental tests include determination of CS, WA and the SC of the fired clay bricks. The plot of mean CS of the fired clay bricks versus firing temperature is presented in Fig 4.

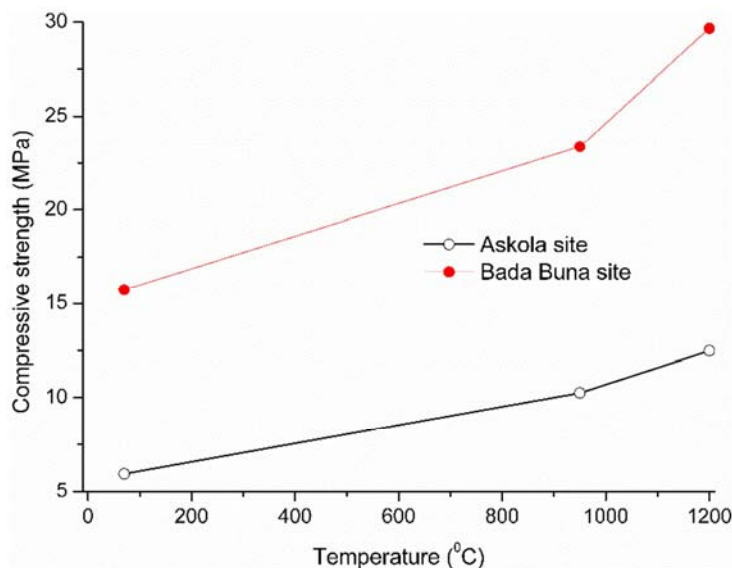


Fig. 4. Plot of mean CS versus firing temperature.

The average CS of five bricks produced using soil samples from Bada Buna and Askola increases as the firing temperature rises from 700 to 1200°C. Particularly the rapid

increment in CS occurs above 700°C (Fig. 4), which could be due to vitrification phenomenon.

The average CS of five bricks separately produced from

the two soil samples and their classification is given in Table 2. The results show the increase of the CS with the increase in the firing temperature from 700 to 970°C. The plot of the

mean CS of the bricks versus duration of firing is presented in Fig. 5.

**Table 2.** Average CS of bricks and their classification.

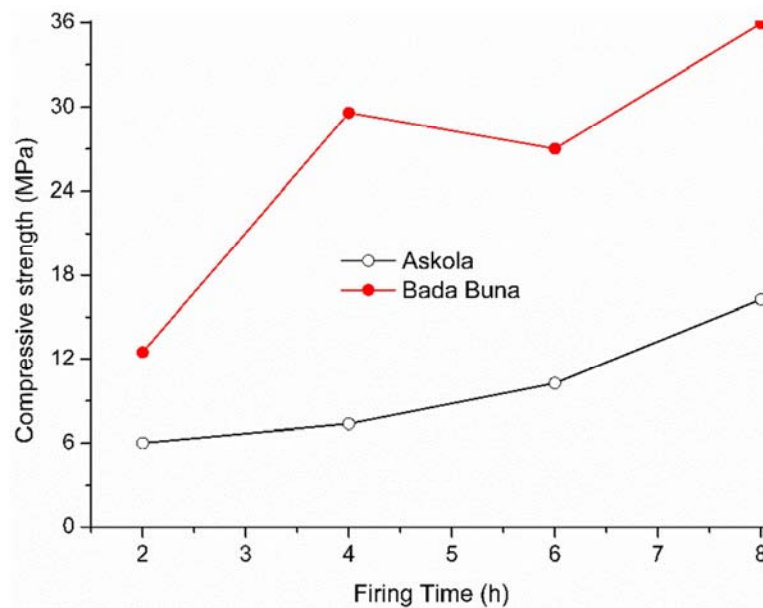
Raw materials	Firing Temperature (°C)	Mean CS (MPa)	Classification	
			(ES 86:2001)	ASTM
Bada Buna	700	15.74	B	NW
	970	23.37	A	SW
	1200	29.67	A	SW
Askola	700	5.93	-	-
	970	10.25	C	-
	1200	12.48	C	SW

It was observed that the clay bricks produced from soil samples containing a larger proportion of white clay soils from Askola started melting at a lower temperature than the one which has a larger amount of red clay soils from Bada Buna. This may imply that the melting point of the white soil sample is lower than the red soil sample. Therefore, the degree of firing is also dependent on the soil type, which depends on the composition of soil parent material. According to the CS results, the optimum firing temperature of bricks produced from Bada Buna site soil samples is from 970 to 1200°C, but the CS of clay brick produced using clay

soil from Askola site has lower CS as compared to bricks produced using clay soil from Bada Buna site. The difference in CS could be the difference in the nature of the soil.

At 700 and 970°C, bricks produced using soil from Askola site, have minimum CS compared with the CS of bricks produced using clay soil from Bada Buna. The difference in CS could be due to variation in mineral content of the soil.

At 120°C, maximum CS is demonstrated by bricks produced using soil from the Bada Buna compared to that of Askola clay soil. The possible reason for this is due to variation of physical properties of clay soil.



**Fig. 5.** CS of bricks produced at 970°C with varying firing duration.

The bricks produced using soil from Bada Buna fired at 970°C demonstrate higher in CS as compared to bricks

produced using clay soils from Askola site as the duration of firing increases (Fig. 3).

**Table 3.** Average WA and SC of bricks and their classification.

Raw materials	firing temperature (°C)	Mean WA and brick classification			Mean SC and brick classification		
		WA (%)	(ES 86: 2001)	ASTM	SC	(ES 86: 2001)	ASTM
Bada Buna	700°C	6.38	A	SW	0.76	A, B	SW
	970°C	6.52	A	SW	0.68	A, B	SW
	1200°C	8.80	A	SW	0.88	A, B	MW
Askola	700°C	17.35	A	MW	0.86	A, B	MW
	970°C	10.80	A	SW	0.66	A, B	SW
	1200°C	19.64	A	MW	0.84	A, B	MW



**Table 4.** WA and SC of bricks produced from Bada Buna and Askola fired at 970°C under different firing duration.

Raw materials	Firing Temperature (°C)	Firing time (h)	Mean WA and brick classification			Mean SC and brick classification		
			WA (%)	(ES 6:2001)	ASTM	SC	(ES 86:2001)	ASTM
Bada Buna	970°C	2	10.01	A	SW	0.84	A, B	MW
		4	7.92	A	SW	0.69	A, B	SW
		6	6.57	A	SW	0.69	A, B	SW
		8	5.58	A	SW	0.69	A, B	SW
Askola	970°C	2	37.51	C, D	NW	0.96	A, B	NW
		4	26.31	C, D	NW	0.82	A, B	MW
		6	12.23	A	SW	0.75	A, B	SW
		8	11.89	A	SW	0.72	A, B	SW

The physical property requirements of fired clay bricks are different in because of the difference in standard specifications of each nation. This is due to the fact that based on the existing weathering conditions. For instance, lower values of WA are required in British Standard Specification for classifying clay bricks when compared with other standard specifications [8, 3].

The mean WA and SC of bricks and classification of the bricks based on WA and SC is given Table 3. For instant based on mean WA, the bricks are classified as a class A according to [8], whereas the same bricks are classified as MW based on ASTM Standard Specification. This shows that classification of fired bricks differs based on different standard specifications. According to the requirement of [8, 14], the clay bricks produced from the same raw materials, from clay soils from Bada Buna site fired at 700°C, as shown in Tables 2 and 3, are classified as class B, A and A, B based

on their mean CS, mean WA and mean WA, respectively.

The mean WA and SC are reduced for all the bricks produced from both soils as the firing temperature increases (Table 3). Moreover, the results of mean WA and SC of bricks produced from Bada Buna site which are fired at constant temperature of 970°C for different duration (Table 4) as the duration of firing increases. The WA and SC of bricks, the important physical properties of bricks, are improved as the firing temperature and duration of firing increase within the optimum firing temperature range.

During the experimental production processes of the fired clay bricks using the clay soils from the two sites, the sizes of the green bricks, the air dried bricks and the fired bricks were measured. Accordingly, it was observed that the sizes of all bricks decreased as the bricks lose their moisture due to drying and firing, and the mean sizes of bricks measured at different stages of production processes are given in Table 5.

**Table 5.** Mean sizes of green bricks, air dried bricks and fired bricks.

Sample site	Size of green bricks (cm)	Mean size of air dried bricks (cm)	Firing temperature (°C)	Mean size of fired bricks (cm)
Bada Buna	25 x 12 x 6	23.2 x 11.2 x 5.9	700	22.60 x 10.58 x 5.60
			970	22.80 x 10.54 x 5.34
			1200	22.62 x 10.26 x 5.36
Askola	25 x 12 x 6	23.1 x 11.4 x 5.7	700	22.60 x 10.54 x 5.40
			970	22.66 x 10.50 x 5.48
			1200	22.62 x 10.60 x 5.44

## 4. Conclusions and Recommendations

Based on the results of this study, the following conclusions and recommendations are drawn:

1. The optimum firing temperature for the production of clay bricks using clay soils from Bada Buna site is from 970 to 1200°C while for the bricks from Askola it is from 900 to 970°C. As the optimum firing temperature increase the CS of the fired clay bricks increases and; the WA and WA of the clay-bricks decrease. This verify that firing temperature significantly affect the physical requirements of fired bricks.
2. Varying the duration of firing from 2 to 8 h under constant firing temperature, causes slight increase in the mean CS and minor decrease in the WA and SC.
3. Physical properties of fired bricks produced from clay soils of the study area at firing temperature of 970 and 1200°C satisfy the Ethiopian Standard Specification for

Solid Clay Bricks (ES 86: 2001). However, clay bricks produced at different firing temperatures have different CS, WA and SC.

4. People involved in the production of fired clay bricks in the study area need to be trained on how to control or financially assisted to buy kiln temperature controlling device.
5. Encouraging both domestic and foreign investments in the brick production sector plays a decisive role to modernize the clay brick production system. Moreover, it creates competition in terms of quality and cost in this sector.

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