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UTILIZATION OF LIMESTONE TO EFFECT ON PHYSICAL - MECHANICAL PROPERTIES OF FIRED CLAY BRICK

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Abstract

Limestone wastes have accumulated in large quantities in countries all over the world. To reduce this materials this work is presented. The goal of this paper is to study the influence of limestone powder on the physical and mechanical of fired clay bricks. It is as replacement of clay, varying the limestone content 5, 10, 15 and 20 wt %. The water / soil ratio is constant 0.3. Three stages of firing are presented to achieve the maximum temperature. The first one is 300 °C and the second one is 600 °C and the last one is 900 °C. Results for the physical properties are showed an increasing of water absorption of clay brick specimens with the limestone content increased, in addition the efflorescence is increased. However, the density and firing shrinkage are decreased with limestone quantity. For the mechanical properties, the results indicate that the clay brick specimens with higher limestone 20 %, showed a decrease in compressive strength and flexural bending strength.

Keywords:

Limestone;
Clay;
Efflorescence;
Shrinkage;
Compressive strength.

1 Introduction

Civil engineers have been faced with the challenge of converting industrial wastes into workable building and construction materials because of the high demand for building materials, especially in the last decade due to population growth, which has resulted in a chronic shortage of building materials. The accumulation of untreated waste, especially in developed countries, has increased environmental concern. Recycling such wastes as building materials looks to be a possible solution not just to the problem of pollution, but also to the problem of construction design that is cost-effective. Research into how this can be done while still fulfilling the material requirements specified in the standards is necessary because the building industry is utilizing environmentally friendly, affordable, and lightweight construction materials with increased incidence.

Recycled limestone waste can be used as a binder, according to current studies of undertaken by academic and scientific researchers [1-5] or aggregate in cementitious materials [3, 6-8], or as a filler in bituminous concrete [9], or manufacturing ceramic materials [10-12]. The interest in researching the possibility of local waste recycling in the manufacture of ceramic materials has grown in response to a few studies that have been published on clay bricks with the addition of limestone waste. It may help to conserve natural resources and reduce waste disposal if recycled limestone waste is substituted in the clay matrix. The transformation to a circular economy depends on the circularity of waste materials produced by the construction industry. A few researchers were investigated of compressive strength for the unfired clay brick unites using straw materials [11].

Currently, limestone blocks are removed from quarries using chainsaws, diamond wire, and diamond saws. The blocks are then cut into smaller pieces that are appropriate for use as building materials [12]. About 20 % of the limestone powder produced during the processing of limestone, including crashing limestone manufacturing, is wasted (LPW). It is reported that the LPW in the UK is 21.2 million tons, 18 million tons in Greece, and 30 million tons in Turkey [12, 13]. In South East Turkey, LPW is buried in landfills or thrown openly into open spaces and unregulated trash pits. Due to its fine texture, it contributes to pollution, dust, and environmental issues. Storms throughout the spring and summer pollute the air, posing a major health risk for people with asthma in particular. Due of the high cost of storage, the industry suffers from LPW storage. In Iraq is liked Turkey and other countries. Studies on potential LPW use strategies in the civil engineering industry are few and far between [12, 13]. Despite the small number of cylinder samples and the fact that they are not on the typical brick sample forms, Galetakis and Raka [13] have conducted several interesting tests. It is found the values for flexural strength and water absorption were not established [13]. Investigations must be done into the additional engineering properties called for by international standards such ASTM C 67-03 [14]. Cupid et al. [15] fired bricks were made by combining clay, sewage sludge, and forest detritus at a temperature of 1000 °C. When compared to conventional burnt bricks, the experiment's brick was shown to be lighter, more thermally and acoustically insulating. Martinez et al. [16] substituted various amounts of sludge for clay in ceramic tiles, mechanical properties, water absorption, and suction showed that adding 5 % sludge to ceramic improved the property.

In this study, different amount of limestone powder 5, 10, 15 and 20 % were replacement as clay soil mixing, moistened with water and prepared in the moulds with compressor. The specimens were cured in dry air 30 - 38 °C for 30 day. The moulds were removed after one day preparing of specimens. All specimens were fired in three stages 300, 600 and 900 °C.

The paper is divided into four sections. The introduction is the first one. The materials and procedures utilized in the experimental study to investigate raw materials and green and fired specimens are provided in the second section. The third section highlights the results and discusses various observations and remarks that help to substantiate the conclusions. The last section is the conclusions of this work, recommendations for additional study are made considering the findings.

2 Materials and methods

The aim of the experiment is to test the influence of utilizing various percentages of prepared limestone as a partial replacement for raw clay of fired clay brick units. Several experiments were conducted on fired clay bricks containing various percentages of limestone, and the results were compared to specimens produced as references without limestone.

2.1 Dry clay soil

In this study, used dry clay soil from Maysan city in southern Iraq, which was dug about 1.5 meters underground (Ebttirah region). As shown in Fig. 1, soil samples were taken, crushed into fine granules, and sieved using a 2.36 mm sieve.

Fig. 1: Dry clay soil sample.

2.2 Limestone

One of the most common types of sedimentary rocks is limestone, which is found in many different places and likely varies greatly in terms of its physical microstructure and chemical composition. Calcite, a mineral with the chemical formula $CaCO_3$, makes up the bulk of limestone, a sedimentary rock. It usually forms in clear, calm, warm, shallow marine waters. Limestone is a type of biological sedimentary rock that forms as an accumulation of shell, coral, algal, fecal, and other organic waste.

The precipitation of calcium carbonate $CaCO_3$ from lake or ocean water is one example of a chemical sedimentary process that might cause its formation. Significant advancements in the thermal properties of limestone can be attributed to earlier research, much of which concentrated on heat-related physical and mechanical properties, such as the effects of heat on the compression strength, ultimate compression strain, color, and mass loss of four limestones mined from the Yucatan Peninsula at heating from ambient to 600 °C [17]. Zhang et al. [18] presented various temperatures, thermal effects on the pore distribution, mechanics, and acoustic emission of limestone. Heat effects on limestone's microstructure by XRD, SEM, and TG-DSC studies at 800 °C [19]. It has been used in different percentages 5, 10, 15 and 20 % as replacement of raw clay to produce fired clay bricks. Due to the mechanical properties (compressive strength) it is used as a mortar to bond the clay brick units of stone units. In addition, it has been high resistant to external influences such as heat, moisture, water leakage and cracking, i.e. limestone has been high physical propertied, see Fig. 2.

Fig. 2: Limestone powder (LPW).

2.3 Water

Tap water was used to prepare the mixtures for all the specimens.

2.4 Mixing and fabrication of bricks

In the lab tests, five different types of mixtures were prepared. Table 1 shows the details of mixtures. The water/soil (W/S) ratio in the mixes was kept constant 0.3 to determine the effects various limestone, herein is used four percentages of limestone 5, 10, 15 and 20 %. The dry soil and limestone content were mixed for 2 - 3 minutes in a steel pan of mixer during the mixing procedure. Water was added to the mixes while the mixer was running in order to produce more homogenous mixtures. The mixtures were then poured into a steel mold with dimensions 3 × 4 × 8.5 cm, steel molds were lubricated to avoid stick clay to the wall of molds.

The mixture proportions listed in Table 1 were used to fill the steel mold. Ten clay brick specimens were prepared from each percentage of limestone for physical and mechanical tests. Fig. 3 shows clay brick specimens were produced for all mixtures. To remove air void in mixtures, compression test machine was used with a maximum capacity of 500 kN. Specimen's thickness was 4 *cm* before pressure load. All specimens have 3 cm thickness after 15 MPa of compressive load was applied for 1 minute in steel mold.

The manufactured clay brick specimens were then taken out of the mold. During the demolding process, the clay brick showed no signs of damage. All specimens were cured at room temperature for 24-hours. Afterwards, clay brick specimens were dried in air dry for 30 days at 30 - 37 °C.

Then, all specimens were fired for three stages 300, 600 and 900 °C in a furnace is 1200 °C is maximum temperature. The stages are included three zones: the first one is preheating for 300 and 600 °C during 65 min., the second zone is firing for 900 °C during 30 min., the last one is cooling during 60 min. The firing and production of the fired clay brick specimens were according to the ASTM C62-04, [20] standard, see Fig. 4.

Table 1: Mixtures proportions for all limestone percentages as replacement clay.

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

Fig. 3: Clay brick specimens for all mixtures 0, 5, 10, 15 and 20 %.

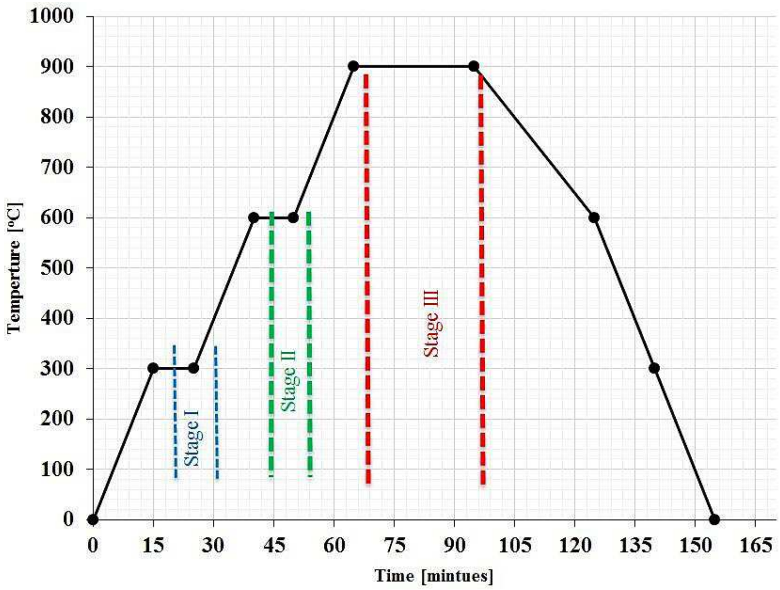

Fig. 4: Temperature-time ranges during the firing of clay brick specimens.

3 Results and discussion

The physical and mechanical characteristics of fired clay bricks, particularly their absorption, efflorescence, density, firing shrinkage, compressive and flexural strengths, significantly vary as a result of the influence of limestone, according to experimental data. The following is a thorough review of the specific qualities.

3.1 Absorption of water

When excess water infiltrates clay brick, it makes the clay swell and hence makes the brick less durable. Water absorption is an important measure of the durability of the brick. The internal structure of the brick must be dense enough to allow a little amount of water to pass through it.

Through the process of the firing of bricks, the crystal structure of the brick will be altered, and clay particles tend to be more packed, hence increasing the density of the brick. In this work, three stage of fire temperature are presented: the first one is 300 °C for 10 min., the second one is 600 °C for 10 min. and the last one is 900 °C for 30 min. The limestone is dissolved at peak temperature 900 °C that cause to form more pores into materials. Therefore, absorption is 35 % for specimens of 20 % of limestone. In the other hand, the absorption is increased with the increasing the porosity. Table 2 represents maximum limits of water absorption percentage of clay bricks according to Iraqi Standards (IQS 25-1988) [21].

Fig. 5 shows absorption-limestone relationship, it can be observed that clay brick specimens with zero percent of limestone in them had the lowest water absorption rate of 19.1 % which means Type A. While the specimens with 5 % limestone in them had the rate of water absorption at 24 % which means Type B.

The last one of specimens with 20 % limestone in them had the highest rate of water absorption at 35 % which means more that maximum limit of IQS 25.

Generally, it was observed that water absorption increased as the percentage of limestone in the clay brick specimens increased, see Fig. 5.

The implication of this test is that during firing, limestone creates voids within the brick structures, the void left behind after cooling must have been filled up with water during the absorption test. Hence the general high absorption rate when compared to the control specimens.

Table 2: Maximum limits of water absorption percentage of clay bricks according to Iraqi Standards (IQS 25-1988).

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

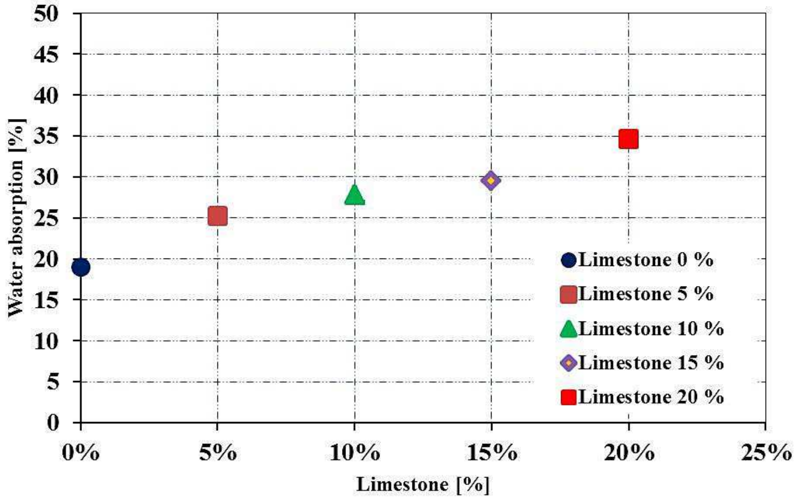

Fig. 5: Water absorption - limestone relationship.

3.2 Efflorescence of clay brick

Salt efflorescence, a characteristic surface issue commonly seen on clay brick, mortar, and concrete facades, is the formation of salt crystals on a surface caused by evaporation of water that included the slats. It mainly involves whitish deposits of water-soluble salts, such as sodium chloride or alkali sulphates, which typically occur shortly after the facade's construction.

All results are presented the effect on efflorescence is positive, i.e. when it is increased limestone caused to increase of efflorescence due to the high absorption of water for limestone, this test is according to ASTM C67-03 [14] standards, see Fig. 6. A 0.1 % value for specimens with 5 % of limestone while this value is reached to 17 % for specimens of 20 % of limestone. At 700 °C the limestone is weakened and dissolved. This phenomenon is influence on porosity of materials. On the other hand, increasing porosity led to increase absorption of water which cause to more efflorescence.

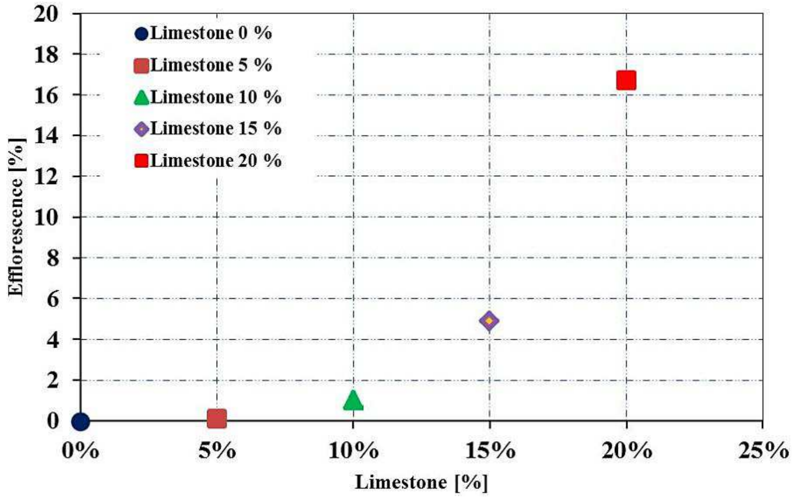

Fig. 6: Efflorescence - limestone relationship.

3.3 Clay brick density

Fig. 7 as shown below is presented the relationship between the densities of specimens with limestone percentages. The density of specimens was measured by dividing the specimen's mass by the calculated volume. Experimental results were found the specimens with limestone lighter than reference specimens (Limestone 0 %). On the other ward, it can be showed the density is decreased – 5 % when limestone is 5 % while this percent is reached to – 19 % for the specimens 20 % of limestone. At 700 °C or more is affected on nature of limestone particles, i.e. the specimens with 20 % of limestone case to more voids into specimen which is influence on weight of specimens. According to some authors, the results of the study revealed that limestone was mostly composed of calcium carbonate $CaCO_3$ and small amounts of dolomite $MgCO_3$, which may have contributed to the specimen's increase in porosity and decrease in density after firing [22]. The density is affected negative with amount of limestone.

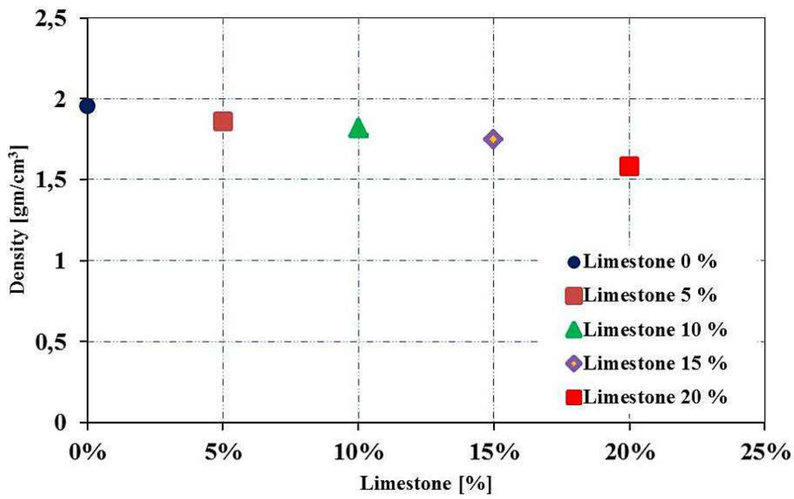

Fig. 7: Density - limestone relationship.

3.4 Firing shrinkage

Linear shrinkage was determined by measuring the volume of the brick sample before and after firing over the whole process using a caliper with accuracy of + 0.01 mm according to ASTM C326-03, [23] standard. The firing shrinkage was expressed as a percentage and calculated using the expression:

$$Firing\ shrinkage\ (\%) = \frac{Vd - Vf}{Vd} \times 100\ , \quad (1)$$

where v_d is volume of the air-dried specimen in mm and v_f is volume of the fired specimen in mm.

Fig. 8 shows the evolution of the firing shrinkage of the four groups of clay brick specimens in addition reference group that were evaluated in this study. Each point on the graph corresponds to the mean of the shrinkage values of three specimens, and the variation range is also shown.

However, the results show the same trend in the intensity of firing shrinkage. The results clearly show that the firing shrinkage rate is higher in the reference specimens (zero percent of limestone). The shrinkage is decreased with limestone content in the specimens. When comparing all four groups with reference, it was found that the highest mass loss corresponded to low values of shrinkage for 20 % limestone specimen. This means that with increasing limestone, greater mass loss (high absorption) was obtained and lower values of shrinkage were found. This behaviour is associated with the fact that the removal of free water from voids in the matrix does not cause shrinkage of the system water. Some of authors were found similar results in this field [24, 25].

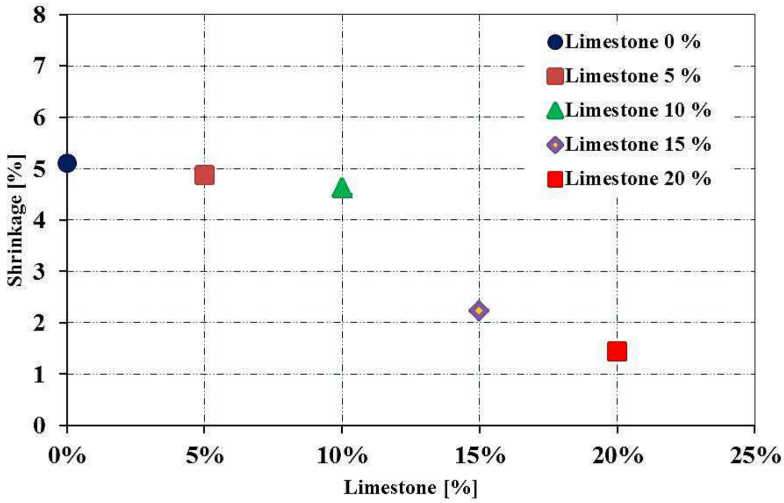

Fig. 8: Shrinkage - limestone relationship.

3.5 Compressive strength

Fig. 9 shows the results of the compressive strength values obtained from the testes, it is according to ASTM C67-03 [14] standards. The average compressive strength values are inversely proportionate with the amount of limestone, i.e. the compressive strength dramatically is decreased with limestone. A 16 % reduction in the strength of the control specimens for the 5 % percentage of limestone, in addition the decreasing is reached 59 % for the specimens with 20 % of limestone. These results are accepted with some authors [25]. The compressive strength is decreased with increasing limestone due to the particles of limestone have been loose of strength at temperature 900 °C in addition it is decompose at high temperature.

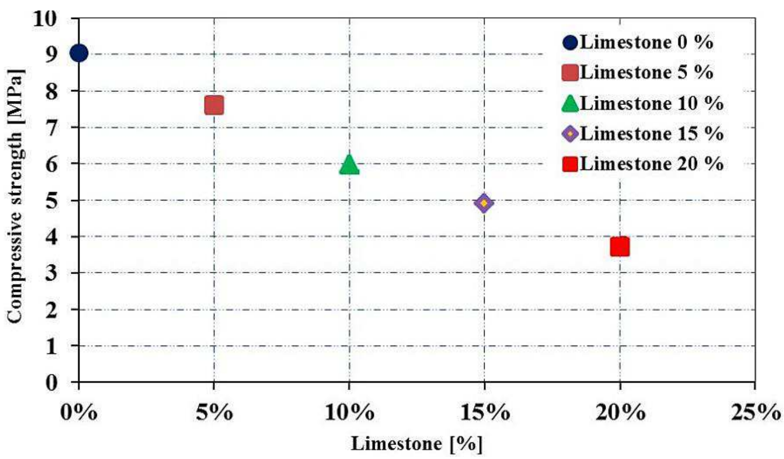

Fig. 9: Compressive strength - limestone relationship.

3.6 Flexural strength

As shown in Fig. 10 for the experimental data of flexural strength for all amount of limestone, this test is according to ASTM C67-03 [14] standards. There is continuous decrease in flexural strength with increase limestone percentage. A 32 % decreasing for specimens with 5 % of limestone while the decreasing is 83 % for specimens with 20 % of limestone. The mechanical properties (flexure) are influenced by temperature. The specimens of clay brick with 20 % limestone are weak of strength, it is resulted formulation of limestone at 700 °C and more.

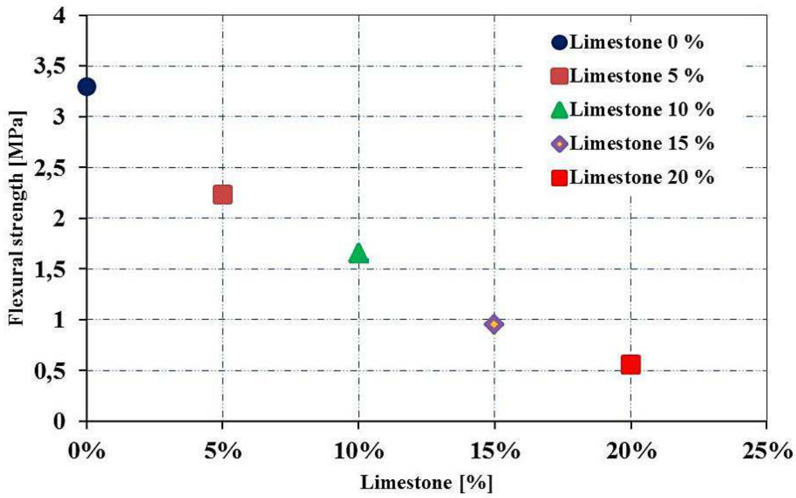

Fig. 10: Flexural strength - limestone relationship.

The flexural strength or modulus of rapture for clay brick specimens is mathematically expressed as below. Fig. 11 shows clay brick specimen.

$$Flexural\ strength\ (modulus\ of\ rupture) = \frac{3F \cdot L}{2b \cdot d^2}, \tag{2}$$

where:
F - failure load in N,
L - distance between supports in mm,
b - width of specimen in mm,
d - thickness of specimen in mm.

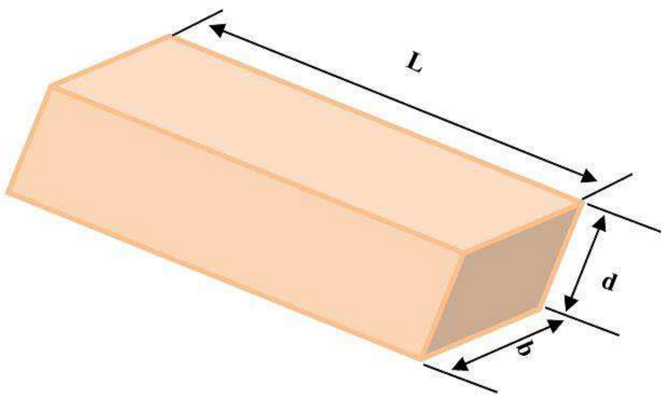

Fig. 11: Clay brick specimen.

4 Conclusions

The experimental results obtained on fired clay bricks materials by replacement of limestone with clay raw materials highlighted the following:

1) The water absorption was increased by 24 % for the specimens with 5 % limestone, so it can be observed the highest absorption up to 35 % for the specimens with limestone 20 %.

2) The efflorescence is seemed similar for the reference specimens and with limestone 5 % specimens. It is positive influence by limestone quantity cased to increasing up to 17 % for specimens with limestone 20 %.

3) The specimen's densities were reduced gradually for the specimens from lowest to highest of limestone percent, i.e. the decreasing of density for specimens with limestone 5, 10, 15 and 20 % were 5, 7, 10 and 19 % respectively.

4) The relationship between firing shrinkage and limestone content was decreased slightly with increased the limestone percent, i.e. these values were 5, 4.6, 2.2 and 1.5 % for the specimens with limestone 5, 10, 15 and 20 % respectively.

5) The compressive strength of specimens with limestone 20 % was lower than that the reference specimens (Limestone 0 %), with up to 59 %, while was up to 16 % for the specimens (Limestone 5 %).

6) Incorporation of limestone in flexural strength, reduced the flexural strength of specimens with limestone and the highest reduction up to 83 % was found to be clay brick specimens with a 20 % limestone replacement percent.

7) According to the physical and mechanical properties for the clay brick specimens with dimensions 3 x 4 x 8.5 cm can be introduced standard clay brick specimens with dimensions 7.5 x 11 x 23 cm.

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