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Producing Lightweight Foam Concrete Building Units Using Local Resources

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Abstract
Brick is one of the most building units used in construction. Locally, this product suffer from many defects; technical, production, specification, and environment impact. Beside the inefficient quality control on the properties of produced building units that lead to negative effects on the overall construction processes. This research aims to produce sustainable alternative bricks using lightweight foam concrete made of local materials to substitute the traditional fired clay bricks. Lightweight foam concrete considered as new construction buildings materials used in construction sector in Iraq, it can produce from available local materials; Portland cement, fine sand, and foaming agent. Detailed information and data was derived from intensive experimental study and laboratory tests for the alternative brick units. Briefly; with density of (1200 to 2000 kg/m^3) and brick size of (230*110*70 mm), lightweight foam concrete (LWFC) bricks were produced with properties can efficiently compete the fired clay bricks. The compressive strength was (4-45 MPa), water absorption (1-26%), thermal conductivity (0.10130-0.25375 w/k.m), and shrinkage (0.011-0.056%), with no efflorescence and very little tolerances in all dimension. these results show that there is a possibility for the use of LWFC units as construction units that can compete the fired clay bricks.
Keywords: Clay Brick, Lightweight foam concrete, Building units, Mechanical properties.

1. Introduction

Bricks is the man – made construction materials and considered one of the oldest manufactured construction materials in the world. The first use of bricks noted was the ancient city of UR in Iraq. The Mesopotamians (Iraq) made bricks from alluvial deposits of the close river Tigris and Euphrates to construct their own houses and these temples. While sun dried bricks were found in the deeper layers of Nile sediment in the Egypt. The knowledge of maintain clay bricks by burning has been recorded. The burnt bricks were developed as archaeological traces discovered in Ancient civilization, such as the basin of Tigris the Euphrates and the Indus that utilize, both fire and unburnt bricks. The Roman utilize the burnt brick and introduces to England, the brick developed to different types and became use in the most countries in the world (Kadir and Mohajerani 2011).

Today, this building units suffer from many defect such as in production, properties, quality and their effect on environmental. To development this manufacture in Iraq, light weight foam concrete bricks can be used as an alternative to fired clay bricks.

Lightweight foam concrete or cellular concrete is a type of lightweight concrete produce by introducing foaming agent to the cement paste. There are no chemical reactions in this method and considered most controllable and economical process, lightweight foam concrete is a mixture of binder or lime mortar .The density of cellular concrete ranges between (300-1900 Kg/m^3) and it can be controlled by changing the quantity of entrained air, also can use LWA in produce cellular concrete to obtain certain properties such as strength, durability and economy (Maldonado et al 2015, Narayanan and Ramamurthy 2000).

Lightweight foam concrete considered new creative green technology material using in sustainable construction (Richard, 2013). It is characterized by many features make it a sustainable materials such as lower density, lower thermal conductivity, fire rating, sound insulation, savings in material, savings in manpower, life span of foam lightweight concrete, eliminate toxics, use recyclable resources and save cost (Mazharul and Alex 2007, Moon and Varghese 2014).

2. Experimental Work

2.1 Materials Used

In this study local materials used to produce lightweight foam concrete bricks (LWFC) as shown below:

1. Cements: in this research type I ordinary Portland cement (OPC) was used. Tasluja is the brand name of cement manufacture by united cement company, it complies with ASTM (C-150) stander specification requirements.
2. Iraq sand: local Iraq sand was used in this research, the particle size of sand was 600 µm.
3. Super plasticizer: Glenium is the brand name of high range super plasticizer that used in this study, it is meeting the requirements of ASTM (C 494M-04).
4. Foam Agent: in this research ARCEL SP20 was used as foam agent, it's not react with crystalized cement on long terms and on short term.

2.2 Proportioning And Mix Design of Foam Concrete

The mix design adopted in this research was 1:1:0.3 by mass of ordinary Portland cement (OPC), sand, water respectively. The University of Dundee developed the mix proportioning and calculate by using this below equation:

$$C + W + F = D \quad (1)$$

Where C = cement (PC and FAf) content, kg/m3

W = water content, kg/m3

F = fine aggregate (sand and/or RSA) content, kg/m³

D = target plastic density, kg/m³

2.3 The Production of Foam Concrete

The procedure of casting and equipment required to produce foam concrete is different from the normal concrete production, so it is need more care when produced. The mixing procedure for producing foam concrete are described by (Jones 2003, Wrap 2007). There are no stander specification are adopted to manufacture LWFC.

The cement and sand (dry materials) combined in the mixer with dry form for the purpose of consistency for half minute, the amount of water added to the dry materials and mixed for 4minuts or waiting until the mortar become homogenous with no lumps of undispersed cement was obtained. The SP add to the mix at the same time of adding 80% of water to the mix, after that the remaining water is added.

After mixing water with dry materials, the pre-formed foam is produce by using foam generator, the foaming agent is mingled with water by 1 liter of foam to 30 liters of water. To obtain the target density, the fresh density of the mix will be measure by using container 1 liter (the value within ± 100 Kg/m^3 accepted).When the fresh density is higher than target density or design density additional foam will be add until obtain the design density, but when the fresh density is lower than target density the mix will be repeated. The LWFC casting in the moulding, finally, the samples weighted directly after removed from the moulding to get hard density and cover with plastic sheet and keep in the lab with room temperature.

3. Test Methods

3.1 Compressive Strength Test

According to ASTM (C-140) the lightweight foam concrete bricks are test after 28 days, the bricks supply to test should keep separately in air at (24+-8C^o) and relative humidity less than 80% for not less than 48h, then placed in the device of compressive strength and used single steel bearing plate to covered the upper and lower bearing area of specimens. The maximum load and compressive strength carried by sample was recorded as shown in figure (1).

Figure 1. Compressive Strength Test for LWFC Bricks and Shape of Failure

3.2 Water Absorption Test

This test was accompanied according to ASTM (C-642) , the units of bricks with (230*110*70mm) are used to determine the absorption of water by LWFC bricks ,the weight of the units was measured before placing the samples in the oven , then place the dried specimen in an oven at a temperature of 100 to 110 C^o for 24 hour , the specimen allow in the air 20C^o after out from oven then the weight is measure , if the initial weight and dry weight is closed the specimen considered dry but if the weight is not closed the samples will be place another 24 hour and the process repeated until the tolerance of two value of sequential weight not exceed 0.5% as shown in figure (2). Then record dry weight and considered as weight (A). The specimen after dry, cooling, and place in the water at 21C^o approximately for 48h and until the sequential weighted is closed less than 0.5%. then this weight considered as wet weight (B), before measurement the weight of units after out from water towel is used to removing the surface moisture, to calculate the water absorption, the following formal was used:

$$\text{Absorption after immersion } \% = [(B-A)/A]*100 \qquad (2)$$

A= mass of oven dried specimen in (Kg)

B= mass of surface dry after immersion in (Kg)

Figure 2. Water Absorption Test for LWFC Bricks

3.3 Thermal Conductivity Test

This test was accompanied according to ASTM (C-177) by using hot guarded plate test is commonly used to measure the thermal transmission properties of homogeneous insulation materials. This method consist of two main plates; hot and cold plate, when start the test the sample placed on a flat plate heater gathering, containing of an electrically central heater surrounded by a protector heater. To prevent the side heat run from the central heater (heated inner plate) and guarantees that heat from the electric heater movements in the way of the sample should keep the same temperature on both sides of the gap separating the heated inner plate and the protector heaters by control on the guard heater. The cold plate is on the opposite side of the specimen, the temperature of this plate is a fixed selected by the operator as shown in figure (3). When the heat input to the heated inner plate the hot plate gathering increases in temperature until the system reaches stability. The final temperature of hot plate depended on the electrical power input. The thermal conductivity is determined by using the Fourier heat flow equation.

$$K = \frac{W}{A}\left[1^{*}\frac{d}{\Delta T}\right] \qquad (3)$$

Where K is thermal conductivity.

W is the electrical power input to the main heater.

A is the surface area of main heater.

ΔT is the difference in temperature and d is the thickness of specimen

Figure 3. Thermal Conductivity Machine and Specimens of Test

3.4 Dry Shrinkage Test

The specimen with (160*40*40 mm) is used to measure the dry shrinkage according to ASTM (C-157), after removing the sample from molds, place in water at (23 ± 0.5 C°) and after 24 ±1/2 hr. out from water and wipe with damp cloth, before taking the reading of specimen steel bar placed in the instrument and take its reading, then taken the reading of sample, this reading is the initial reading as shown in figure (4). After 28 days of wrapped curing the final reading is taken for sample with steel bar. To calculate the dry shrinkage this formula can used:

$$\Delta L_{x=} [(CRD - \text{initial } CRD)/G]*100 \quad (4)$$

Where ΔL_x =length change of sampling at any age %

CRD= difference between the reading of sampling and the reading of steel bar at any age

G= the length of specimen

Figure 4. Dry Shrinkage Test

3.5 Acoustic Insulation Test
This test was accompanied according to ASTM (E-336) by using local device in University of Technology (Materials Engineering Department). The device consists of four parts. The test start by placing the sample in the middle of wooden box and close the box, then wave generated with different frequencies by using wave generator device, this wave will amplified by device to amplify the wave and transferred to a loud speaker attached with box pass through the specimen. The received wave measured by the receiving wave device.

3.6 Efflorescence Test
This test was accompanied according to ASTM (C-67). The bricks selected to test should be clean and removed adhering mud that might be incorrect for efflorescence. Then placed in containers made of material free soluble salts, the dimension of containers should be provided 2.5 cm depth of water and the total volume of water in containers is large in comparison with the evaporated quantity each day. The containers placed in the drying room for 7 days in the same period another five bricks is stored in drying room without contact with water after the end of this period the test bricks compare with the bricks in the dry room and dry in oven for 24 hrs. And seeing the upper and all four faces of each sample.

3.7 Dimension Test
According to ASTM(C-140) the steel scale use to measure the overall dimensions, the face of brick measure with a caliper ruler, for each unit, measure and record the height at mid-length, the width at mid- length and the length at mid-height of each face, and determine the average of the measurement , the measurement was take after 28 days.

4. Results and Discussion

4.1 Compressive Strength of Foam Concrete Bricks

The compressive strength is the most important physical property that identify the possibility of use foam concrete bricks in structural application (bearing and non-load bearing bricks).There are many factor influence on the compressive strength of LWFC brick such as density, Water/cement ratio, sand/ cement ratio, the type of sand, Curing method and quantity of air-voids in the hardened foamed concrete varies. In figure (5) we can note that compressive strength directly affect by density when the other factors is constant, where a decrease in density leads to decrease in the compressive strength. These results completely comply with finding of Suhad and Abbas (2015).

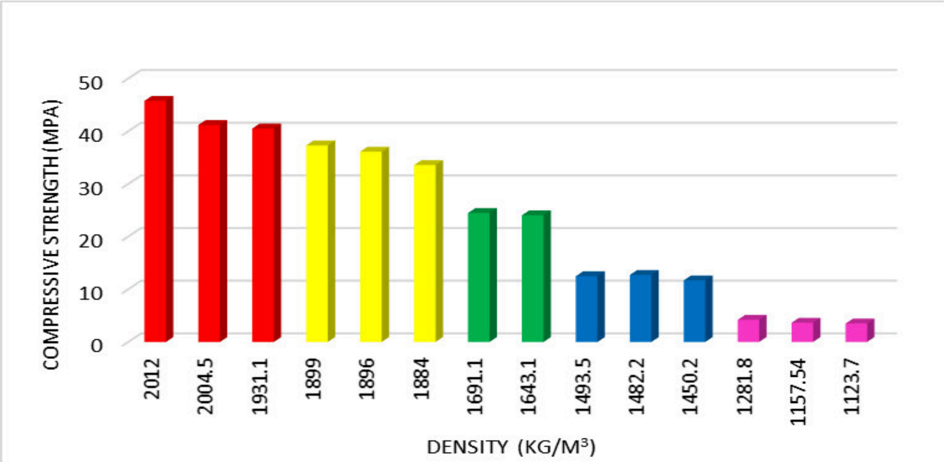


Figure 5. Compressive Strength of Foam Concrete Bricks with Various Densities

In order to check if the results are acceptable should compare with specification. The ASTM (C90-01) and ASTM (C129-03) specification for load bearing and non- load bearing concrete masonry units identify the minimum compressive strength is 11.7 Mpa for one brick for load bearing masonry units and 3.45 Mpa for non-load bearing masonry units. When compare the results above with specification can determine that densities range from (2000-1400) can considered as load bearing bricks units and density 1200 can considered non-loading bricks units as shown in table (1).

Table 1. Compare the Results of Compressive Strength with ASTM (C90-01 & C129-03) For Load Bearing and Non- Load Bearing Concrete Masonry Units

Actual Density	Compressive Strength (MPa)	Classification of bricks load and non-load bearing	ASTM Min requirement (MPa)
2000	45-40	Load bearing	≥ 11.7 (C90-01)
1800	37-33	Load bearing	
1600	24-22	Load bearing	
1400	12-11.7	Load bearing	
1200	4-3.5	Non-load bearing	≥ 3.45 (C129-03)

4.2 Water Absorption of Foam Concrete Bricks

The ability to absorption water is an important factor affect on the durability of bricks, the durability quality of foam concrete bricks can be expressed in terms of low water absorption. The relationship between the density and the ability absorption of water is linear, when the density decrease the water absorption increase. In figure (6) the results of water absorption test conducted on the foam concrete bricks show that the amount of water absorbed by foam concrete bricks various with density. The high density 2015.8 Kg/m^3 has low water absorption 1% and the lower density 1188.6 Kg/m^3 has water absorption 26.9% this back to the large amount of foam addition to the mixture to obtain lower density that produce large amount of air-voids that filled with water, while the high density has less foam content and few air-voids that may fill with water. These results completely comply with finding of (Kearsley and Wainwright 2001), (Antoni et al 2011) in term of water absorption with density of foam concrete.

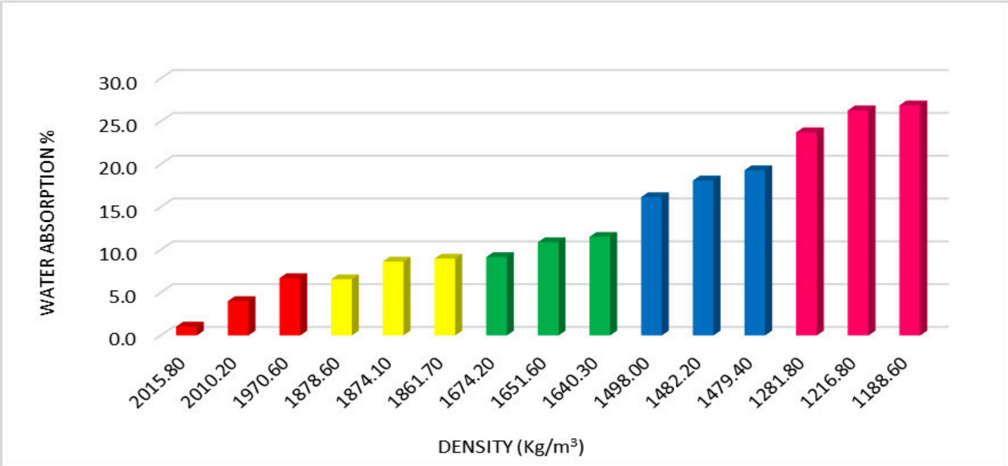


Figure 6. Water Absorption of Foam Concrete Bricks with Various Densities

The water absorption is another important physical property identify the use of bricks as load or non-load bearing. The ASTM C90-01 identify the minimum value of water absorption allow according to density as shown in the table (2).

Table 2. Compare The Results Of Water Absorption With ASTM (C90-01) For Various Densities Concrete Masonry Units.

Actual Density	Water Absorption Kg/m^3	Classification of bricks to load and non -load bearing	Concrete Type (ASTM C90-01)	Water Absorption Limits for Load Bearing (Kg/m^3)
1998.9	77.4	Load bearing	Normal weight	≤ 208
1871.5	136.1	Load bearing		
1655.4	180.5	Load bearing	Medium Weight	≤ 240
1486.5	262.8	Load bearing		
1229.1	300.8	Non-load bearing	Light weight	≤ 288

4.3Thermal Conductivity

The thermal conductivity of LWFC bricks different with density and the excellent insulating property of LWFC is attributable the numerous number of closed cavities creating the multi-cellular structure. In this study, different densities of LWFC were cast and tested. Each density gives various influence on the properties of LWFC. Density of LWFC affected by the quantity of foam added into the mix. The results shown in figure (7) appear that the thermal conductivity of all LWFC samples is positively proportionate with the density. The thermal conductivity decrease with decrease density from 0.25375 to 0.10130W/m.k, when decreasing density from 1951 to 1253 Kg/m^3 due to large quantity of foam was necessary to produce low density LWFC and cause numerous porous. Similar results have also been determine by Mydin (2012), Awang et al (2012), Krishna (2012), Bready 2001 and Vilches et al (2012).

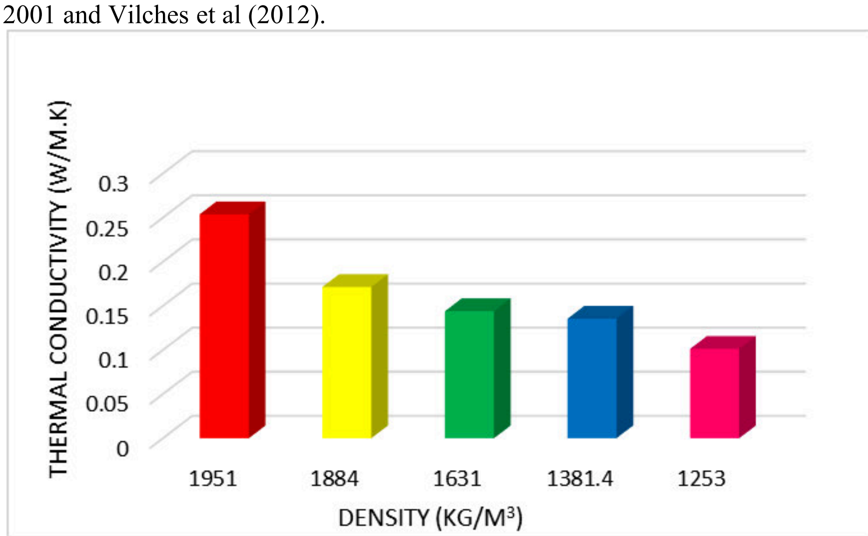


Figure 7. Thermal Conductivity of Foam Concrete with Various Densities

4.4 Dry Shrinkage

Drying shrinkage is occurred by draw water from concrete kept in unsaturated air. Through the process of drying, first when loss of free water cause little or no shrinkage; while drying continuing adsorbed water will extract and the variation in the size of unrestricted hydrated binder paste at that period is approximately the same to the lack of a water layer one molecule thick from the surface of all gel. LWFC includes air as filler as an alternative of strong aggregate which has zero restrain towards the shrinkage of paste , when the foam content increases will increase porosity , decrease density, decrease rigidity of LWFC and cause to remove the water from pores and this will leads to occur the drying shrinkage in LWFC. In figure (8) the results of dry shrinkage test conducted on the foam concrete show that that the dry shrinkage of LWFC increase from 0.01 to 0.056 when density decrease from 2100 to 1201 Kg/m^3. This results refers that the value of drying shrinkage tends to increase with decreasing density. Babu (2008) found the same results.

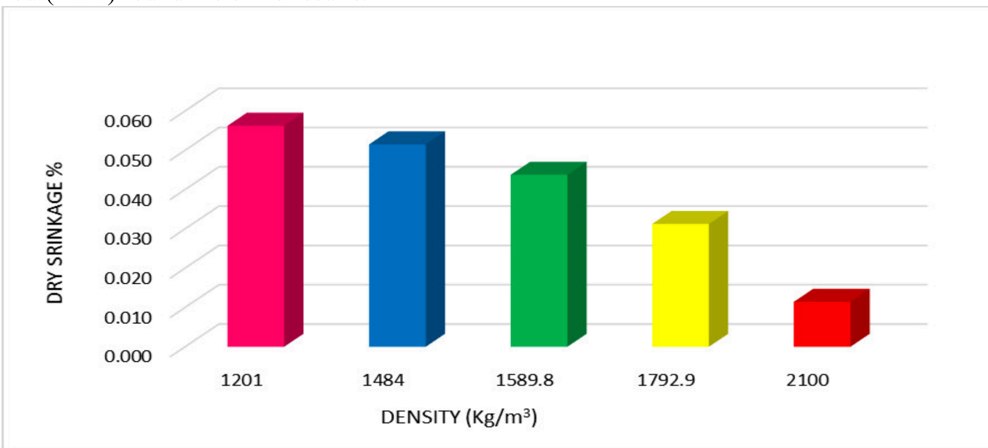
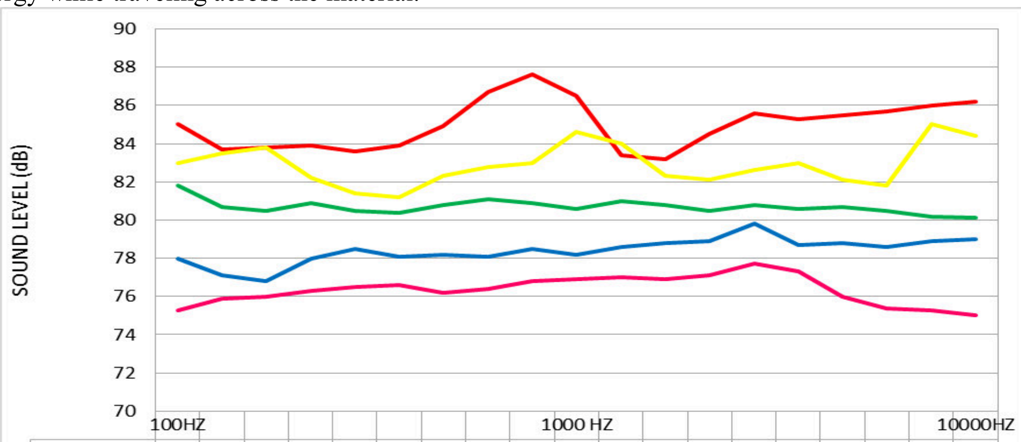


Figure 8. Dry Shrinkage of Foam Concrete with Various Densities

4.5 Acoustic Insulation

Acoustic insulation is one of the most important characteristics of building materials. There are two acoustic properties of a building material sound absorption and sound transmission, Sound waves expand through the air, and if they hit a flat or reflective surface, they will be reflected with the same intensity at which they were emitted. If the sound wave hits a porous surface, part of the energy will be absorbed by the object. In figure (9) the results of acoustic insulation test conducted on the foam concrete show that that the sound level pass through LWFC sample decrease with decrease density due to existence of pours that absorbed the sound waves that loses energy while traveling across the material.



2041	85	83.7	83.8	83.9	83.6	83.9	84.9	86.7	87.6	86.5	83.4	83.2	84.5	85.6	85.3	85.5	85.7	86	86.2
1724.9	83	83.5	83.8	82.2	81.4	81.2	82.3	82.8	83	84.6	84	82.3	82.1	82.6	83	82.1	81.8	85	84.4
1668	81.8	80.7	80.5	80.9	80.5	80.4	80.8	81.1	80.9	80.6	81	80.8	80.5	80.8	80.6	80.7	80.5	80.2	80.1
1481	78	77.1	76.8	78	78.5	78.1	78.2	78.1	78.5	78.2	78.6	78.8	78.9	79.8	78.7	78.8	78.6	78.9	79
1267	75.3	75.9	76	76.3	76.5	76.6	76.2	76.4	76.8	76.9	77	76.9	77.1	77.7	77.3	76	75.4	75.3	75

DENSITY (Kg/m3)

Figure 9. Sound Level of Foam Concrete with Various Densities

4.6 Efflorescence

Efflorescence is describes a white, powdery deposit of crystallized water-soluble salts left on the surface of bricks as the water evaporates. The main reason of appearance efflorescence in the bricks are Sodium Sulfates (Na3S04) and Potassium Sulfates (K2S04) sulfates of calcium and sulfates of magnesium. The results of efflorescence test conducted on the foam concrete bricks are shown that the LWFC bricks showed no efflorescence this indicate that the component of LWFC bricks mixtures (cement, sand, water, foam agent) empty from sulfates that cause efflorescence and this result reported also by Marunmale and Attar (2014).

4.7 Dimension

The tolerances in the dimension of foam concrete bricks is very small when comparing with design dimension (230*110*70mm) due to their manufacturing process. The results of dimension test conducted on the foam concrete bricks are shown in table (4) .LWFC bricks showed very small tolerances.

Table 3. Design Density and Length, Width, Height of LWFC Bricks

				Tolerances		
Density (Kg/m^3)	Length (mm)	Width (mm)	Height (mm)	Length (mm)	Width (mm)	Height (mm)
2000	229.8	110.03	70.05	0.2	-0.03	-0.05
1800	229.9	110.02	70.2	0.1	-0.02	-0.2
1600	230	110.04	70.1	0	-0.04	-0.1
1400	230	110.1	70.02	0	-0.1	-0.02
1200	229	110	70	1	0	0

5. Conclusions

The investigation of the properties of LWFC units according to the standard specifications present many conclusions which can be listed as below:

1. For the densities (1400 to 2000 Kg/m^3) the building units are suitable for load bearing construction, and for density around 1200 can considered as non-loading units.
2. The water absorption for higher density (2000) Kg/m^3 was less than 1%, meanwhile for the lower density (1200 Kg/m^3) was 26.9%
3. Thermal conductivity of LWFC units decrease with density decreasing. It was 0.254 to 0.101 W/m.k, for density (1253 to 1951 Kg/m^3).
4. Dry shrinkage of LWFC units increased from (0.01 to 0.056 mm) when density decrease from (2100 to 1201 Kg/m^3).

The results of acoustic insulation show that these properties decrease with density increasing, the lower density the better in sound insulation. Meanwhile for and dimension tolerances, the higher density the lower in dimension tolerances. The LWFC units showed no efflorescence; this indicate that the component of LWFC mixtures empty from sulfates that cause efflorescence.

Finally, these results show that there is a possibility for the use of LWFC units as construction units that can compete the fired clay bricks.

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