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Preparation Foam Brick from Iraqi Local Clay

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Abstract. In this study, foam bricks prepared by direct foaming method, using local kaolin clay as raw materials, which are available, local, cheap, environmentally -friendly materials and can be recycled. Foam bricks prepared by depend mechanism evolution of gas in situ using several of variables (ratio of clay mixture, ratio of foam solution, ratio of forming mixture and firing temperature) so that one of these variables is fixed randomly after preliminary test and another change in a gradual regular. Then select the optimum value to return randomly and thus after that select optimum values of these parameters for the production of foam bricks. The porosity, thermal conductivity, and compression strength were examined at (9050, 1050)ºC. Porosity, thermal conductivity and compression strength have been investigated at (9050,1050)ºC, SEM and XRD also carried out at specimen firing at 950ºC. The results showed that the optimum foam bricks was obtained with the ratio of clay mixture mullite:kaolin (60:40), agent solution ratio agent:water (1.5:20)and(2.5:20),respectively and forming mixture ratio clay mixture:agent solution (51.14:48.86) at firing temperature950ºC.The specimens prepared in this way have apparent porosity (as high as 0.46%), exhibiting considerable compressive strength (exceeding 5MPa) and low thermal conductivity (about 0.36 (W/m k).

Keywords: Foam brick, foam agent, thermal insulation, lightweight, kaolin, mullite, building and construction solids.

1. Introduction

The topic of energy conservation has become one of the most important topics in the present-day, due to the increasing rates of energy consumption in buildings as a result of the use of heating and air conditioning methods to secure a comfortable atmosphere [1].

The use of heat insulating materials in buildings is considered one of the most important economic means used to reduce the growing energy consumption as it provides an abundance of energy consumed in heating and cooling. In general, heat insulating materials are classified into two groups, organic insulation materials, and inorganic insulation materials. Organic insulation materials, such as polyurethane foam, often have many disadvantages, such as combustion, environmental toxicity, and adhesive incompatibility with concrete and ceramic structures [2].

In addition, organic insulation materials usually exert short working life, for example, foam plastic has a thermal resistance and durability of 8 years or less. However, inorganic materials are superior construction insulation materials, which have many advantages compared with other thermal insulation materials, including chemically inert, non-combustible, chemically stable, long-time stable in physical properties, environmentally friendly, and long use life [3, 4].

Porous materials are the composite of the solid phases and the pores formed through the solid phases, and the existence of pores is the main difference between such materials and other solids. Porous ceramics are either a more open porosity surrounded by a web of ceramic or foam (closed porosity in a continuous ceramic matrix) [5]. These porous network structures have relatively low density, light weight, and thermal insulator. Permeability is high in reticulate and low in foam ceramics due to the open-versus closed-cell structures, respectively [6].

Ceramic foam is porous brittle materials with closed, fully open, or partially interconnected porosity. It can be produced from a broad range of ceramic materials, magnesium silicate, Y-FSZ, Al2O3, TiO2, MgO, mullite, cordierite, etc , that are being considered for the diverse area of potential applications. Ceramic foams consist of cellular structures composed of a three-dimensional network of struts, It can be classified as thermal insulate and lightweight materials that exist as a cellular body, brace, and windows.

Najar et al (2014), study demonstrates the potential utilization of red mud for the production of light weight foamed bricks .The salient features of this brick produced by heat treatment (1000-1200)°C of admixtures containing red mud, fly ash and foaming agents The products light weight foam brick of standard size construction bricks were characterized with approximate (1.2 -1.4) kg weight, (0.93) g/cm3 dry density and (0.32%) porosity value. It has a compressive strength of 8.9 KN and thermal conductivity (0.15) Wm/K at. Further, itwas characterized with stable color, zero efflorescence, and no deformation on exposure to sunlight, rain water, and moisture [5].

Wan Mastura et al. (2017) have manufactured foam brick by using fly ash and foaming agent. The mixture parameters analyzed with fix ratio of (sodium silicate: sodium hydroxide solution) mass ratio 2.5, fly ash/alkaline activator solution mass ratio 2.0, foaming agent/paste mass ratio 1:2. Different curing temperature (25, 60, and 80) ºC and foaming agent/water mass ratio (1:10 and 1:20) were studied. Compressive strength, density analysis and water absorption has been investigated. The results show that the foamed bricks with a lower foam/water mass ratio (1:10) and high curing temperature (80)°C leading to a better properties. Mixtures with a low density of around 1420 kg/m3 and a compressive strength of around 10 MPa were achieved [6].

In this study foam brick is prepared as foam insulating materials. Clay based ceramics are often used for foam brick production, kaoliniet select in this study to preparing foam brick as it is a cheap and readily available raw material Kaoliniet is a simplest clay mineral and mix it with different ratio of mullite to enhanced mechanical proprieties which is characterized by its mechanical resistance [7].

2. Materials and Methods

2.1. Materials

Kaolin is obtained from Establishment of Geological Survey, in Baghdad, Iraq. (Western Sahara mines site). It contains a high percentage of (SiO2) as show in Table 1. Kaolin is Iraqi clays. Kaolin rocks were crushed by a crusher machine and then milling and sieving by use a Sieve Shaker to obtain powder in size ≤63μm,Mullite phase obtained by firing kaolin powder in furnace at 900 phase, it has the composition 3 $Al_2O_3.SiO_2$ or $2Al_2O_3.SiO_2$ and its best known of ceramic proprieties, the mullite phase mix with kaolin in different ratio to produce material with high percentage ofmullite phase and decrease glassy phase and which is stable phase have good mechanical proprieties, Hexane is an alkane of six carbon atoms, with the chemical formula C_6H_{14}. They are all colorless liquids, odorless when pure, with boiling points between 50 and 70°C (122 and 158°F) widely used as cheap, relatively safe, largely uncreative, and easily evaporated non-polar solvents [8, 9].

2.2. Methods

Foam brick was produced by mixed kaolin and mullite phase in different weight ratio together and then mix with foam solution which prepare by adding foaming agent (hexane) to water in different weight ratio , during mixing air bubbles generate the clay slurry mixture were recognized as the mixture volume increases and then wet foam slurry of kaolin, mullite phase and foaming solution components was transferred into molds and let it to dry at room temperature for 24 hour, After that the molds were removed and dry foamed bricks after that firing at 2 different temperatures of 950ºC and 1050ºC for 5 hours with soaking time of 2 hours using (Naberthermp310-Germany) Fig. (1) shows work chart of prepare foam brick specimens.

3. Testing

3.1. Apparent Porosity (A.P)

The porosity of a material is determined by the total pore volume divided with the total volume of the material and it is often expressed as percentage. There are two major classifications of porosity: open and closed. Closed porosity may also be referred to as internal porosity and is the ratio of the volume of void space within the material that is not accessible from the exterior, to the bulk volume Open porosity, which can also be called apparent or interconnected porosity, is the ratio of the volume of void space within the material that is accessible from the exterior, to the bulk volume [10].

The apparent porosity is related with Water absorption, which represents the amount of water absorbed by the open pores. And apparent density is the ratio between mass and apparent volume, which includes only material and closed pores [11] using (ASTM) (C373).

$$(A.P)\ \% = W_s - W_d / W_s - W_i \times 100\% \quad (1)$$

Where:

W_d, Mass of the arid Specimen (g).

W_s, Mass of Specimen is inglorious in Water (g).

W_i, Mass of Specimen being saturated in water (g).

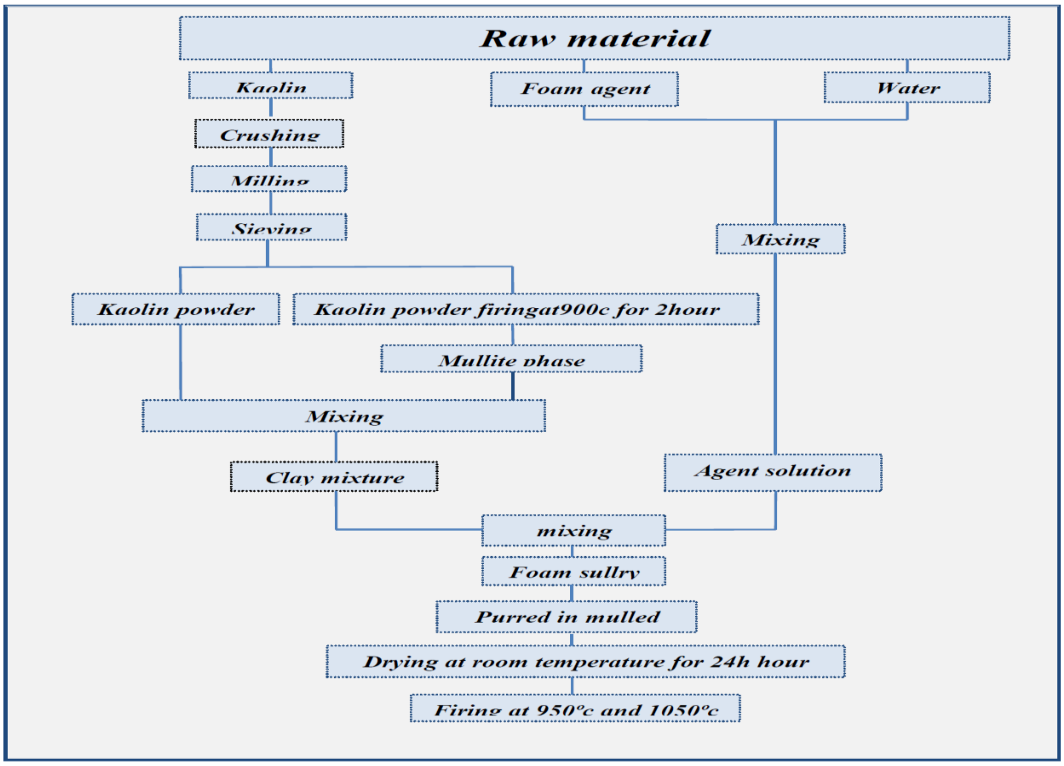


Fig. (1) Work chart of Specimens

Table 1. Chemical analysis of kaolin by XRF.

Material	SiO2	Al2 O3	CaO	fe2O 3	TiO 2	K2 O	Na2O	MgO	SO3
kaolin	49.38	35.7 2	1.19	2.07	1.08	0.44	0.22	0.18	0.05

3.2. Compression Strength

The strength of the ceramic product is one of the governing properties for selecting specific application areas. The strength related to the sort of material, size and shape of the object as well as on the material of which it is made and method of fabrication. Brick foam must resist loading which is generally expressed as the stress on the component. Stress is force per unit area over which the force acts and is expressed as [12]:

$$\sigma = F/A \qquad (2)$$

Where:-
σ is the compression strength (MPa)
F is the applied load (N),
A is the cross-sectional area (m2).

3.3. Thermal Conductivity

Thermal conductivity performance is a great significance of construction materials, as the thermal conductivity influence the usage of the material in engineering applications. The

thermal conductivity of a brick is the rate in which brick conducts heat. Heat losses from buildings is dependent on the thermal conductivity of materials in the walls and roofs [13] a. The thermal conductivity of bricks and other construction materials depend on the density and porosity ratio of the material.
The property that characterizes the ability of material to transfer heat is the thermal conductivity which is a measure of the ability of a material to conduct heat; it is expressed in equation [10].

$$dq/dt = -k\,A\,(dT/dx) \quad (3)$$

Where
dq/dt:be a sign of; indicateheat flux per unit time
A: the cross-sectional area normal to direction of heat flow (m2)
K: the thermal conductivity (W/m .k)
dT/dx: is the temperature gradient through the conducting medium [13].

3.4. Scanning Electron Microscopy

The fracture surface of foam brick samples were studied under scanning electron microscope (SEM) at 10000 X magnification. The scanning electron microscopy (INSPECTS50, No. 9922650, made in the Netherlands) is used to investigate the microstructure of foam brick.

4. Results and Discussion

Manufacturing process foam brick include large number of variables or factors (type of materials, percentage of materials, the variable of method used to generate foam, fairing temperature,….) which dramatically affect in the physical, mechanical, thermal and characteristic properties of final product, porosity is consider the main propriety of foam product which correlated to the foam density .The porosity in the ceramic product depends on two factors involved:
•The production or formation process
•The sintering process variables, before burning process ceramic body is highly porous, and most of the pores are open and continuous , during the last stage of the burning process the big open pores and turns into small closed pores, and a large number of closed pores fade in the last stage of burning, porosity is an important parameter that influences the properties and performance of foam brick Hence, an attempt is made to reveal relations between porosity and compression strength and thermal conductivity in this work .Thermal conductivity is a effective factor for thermal insulating product .The porosity in the ceramics is intrinsically related to thermal conductivity, i.e. porosity in the ceramics reduce the energy requirements by stop transfer of heat.In general, porous materials have low thermal conductivity and there for serve as insulation materials. Thus, closed and small air spaces in a material are effective in reducing the thermal conductivity as the thermal conductivity in gases is much lower than in solid material J and also mechanical strength of porous ceramics is independent on the pore morphology and structure which are mainly determined by the processing technique applied. Therefore, the relationship between the porous structure and the compressive strength behavior must be well understood in designing novel pore microstructures with desirable strength. The strength of porous ceramic may be controlled by factors such as density, porosity and phase presented after sintering. The most influential factor that control the strength of porous ceramic is the porosity due to the fact that the pores produced were inter granular thus affected the strength. In addition, porous ceramic structure, does not undergo plastic deformation due to it is a type of brittle material. In order to prevent the foam ceramics from being damaged and cracked during transportation and construction, must to have a compressive strength to be as acceptable as possible(foam ceramic).so there is an important relationship between its properties, porosity, thermal conductivity, and compression strength [13-15].

4.1. Stage 1

To produce foam brick with high porosity, high thermal insulator and acceptable value of compression strength there for preliminary tests include several of variables are (mullite ratio, foam solution ratio, clay mixture ratio and firing temperature) so had been fixing one of this variable randomly and change another gradually regular and then select optimum value to return randomly and thus after that select optimum values of these parameter to produces optimum foam brickas shown in Fig. (2) which indicate work steps.

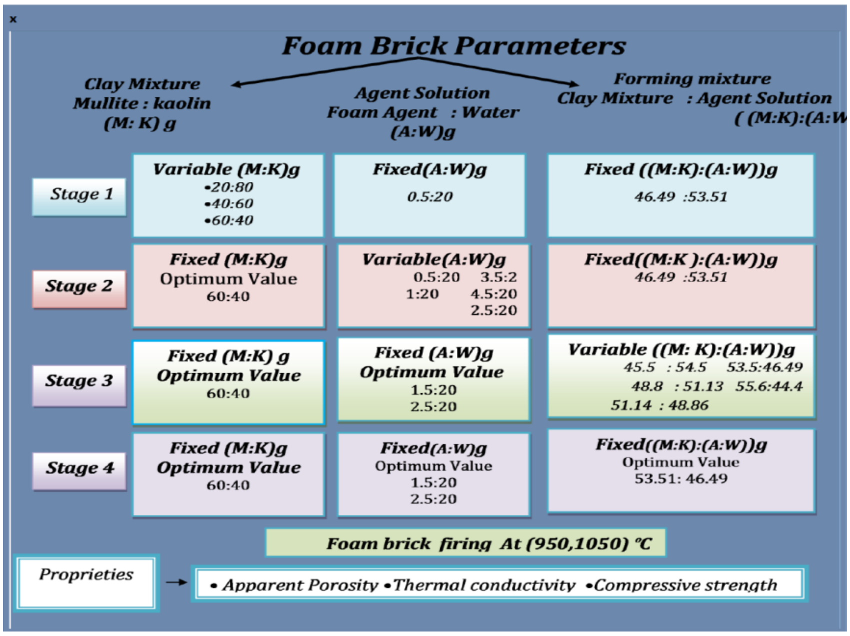


Fig. (2): work stage.

In this stage fixed the agent solution ratio and forming mixture ratio randomly and change the clay mixture ratio gradually.

Figs. (3-5) shows the apparent porosity, thermal conductivity and compression strength respectively with versus different ratios of(Mullite :kaolin) for foam brick firing at (950, 1050)°C.

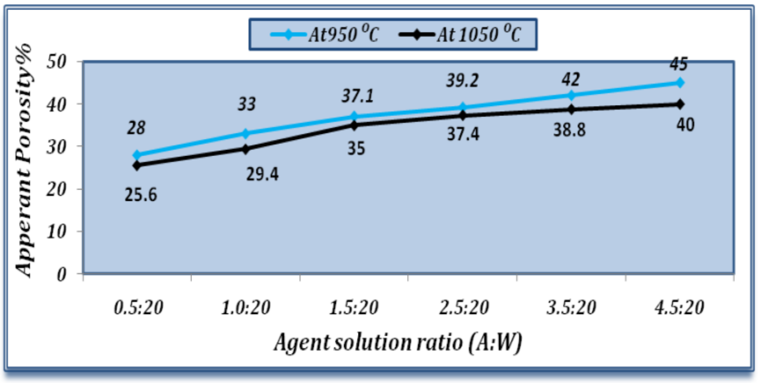


Fig (3). Effect of clay mixture ratio on Apparent Porosity.

4.1.1. Apparent Porosity

Porosity increase as the Mullite ratio increase as show in Fig. (3), for the Mullite is the constant stable phase of crystal structure (3Al2O3.2SiO2). It does not convert into a new structure in the thermal range of firing from (950-1400)°C, the increase in Mullite ratio is offset by a decrease in the ratio of kaolin, that is, a decrease in the proportions of the raw materials that form the glass phase in the final firing stages, which fill the pores, so an increase in the percentage of voids and porous occurs [11].

4.1.2. Thermal conductivity

The increase in porosity lead to reduction in thermal conductivity and this shown in Fig. (4) since heat movement in heat-insulating materials by the phonon which is generated by the vibration of crystal structure the presence of pores obstructs the movement of the phonon and prevent of its movement from hot area to cold area, this is result agreement with Abdul Kadir et al. (2010) [6].

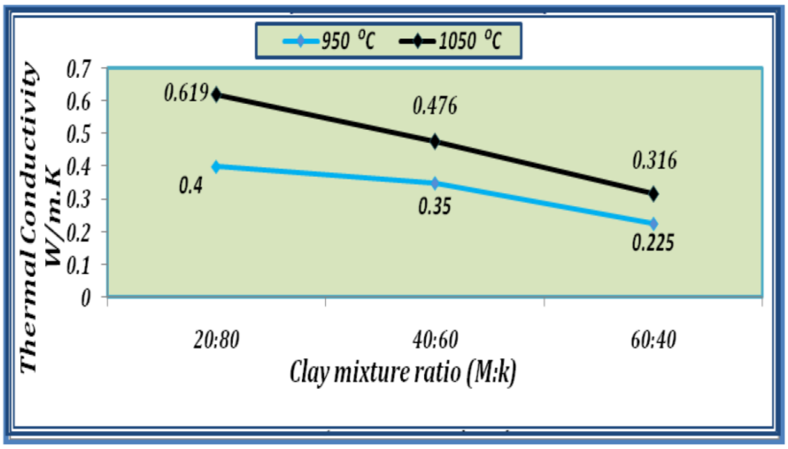


Fig. (4). Effect of clay mixture ratio on Thermal Conductivity

4.1.3. Compressive strength

Increased porosity leads to decreased compressive strength as shown in Fig. (5) for the increase in porosity phase decrease in Mullite phase which is bear the load and stress and distributed it homogeneously.

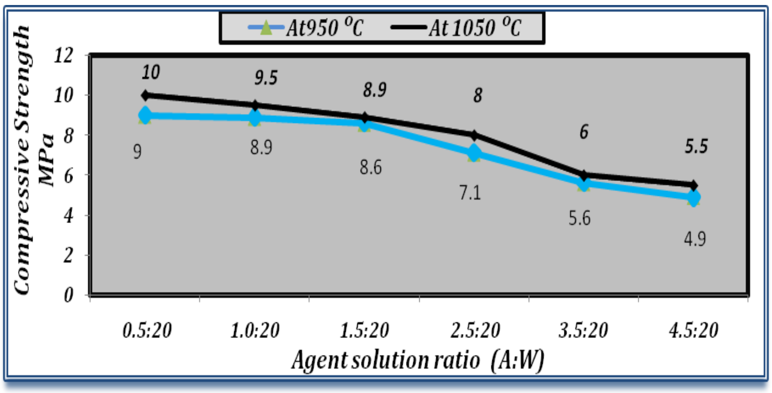


Fig. (5). Effect of clay mixture ratio on Compressive Strength

As the firing temperature increased the apparent porosity decreased due to the decrease in viscosity of liquid phase where it is more effective to fill pores also as firing progresses, pores were rounding and becoming smaller and completely isolated from the surface at the end of firing, and then closed, liquid phase which formation from fusion of silica mainly add to fusion of oxides(K_2O, CaO, FeO_2, TiO, Fe_2O_3,..) found in ceramic clay .Through the previous fig ,it was found the clay mixture ratio 60:40 of Mullite : kaolin is represent the best ratio to have maximum value of apparent porosity , minimum value of thermal conductivity and acceptable value of compression strength [14-16].

4.2. Stage 2

In this stage the ratio (60:40) of Mullite : kaolin have been fixed to its represent optimum value as indicated in stag 1 and the forming mixture ratio fixed randomly to study the effect of increment of foam agent weight to water versus the apparent porosity ,thermal conductivity and compression strength for foam brick fired at (950, 1050)°C respectively as indicate in Figs. (6-8).

4.2.1. Apparent porosity

To evaluate the properties of foam brick, preparation foam brick by mixing materials with agent solution to make a homogenous foam emulsion, where foam agent was well distributed. During the foaming process agent votallized and then produced pores in brick body and then, at the beginning of the firing process at (150)°C, the ceramic body loses the water present due to moisture and the remaining water from the solution produced pores in brick body behind .When the temperature reaches 450°C and more, the ceramic body loses crystallization water and at (700-900)°C the impurities such as organic matter firing and produced pores after 900°C glass phase resulting from the fluxes oxides help with silica in melting which fill the pores. Greater fluxes percentage of agent, means greater percentage of pores formed during the process of forming, thus increasing the ratio of pores volatilized causing the formation of bubbles during the forming process that’s shown in Fig. (6), Mohamed Najar et al (2014) reported that the apparent porosity increased as foaming agent increased [5, 17].

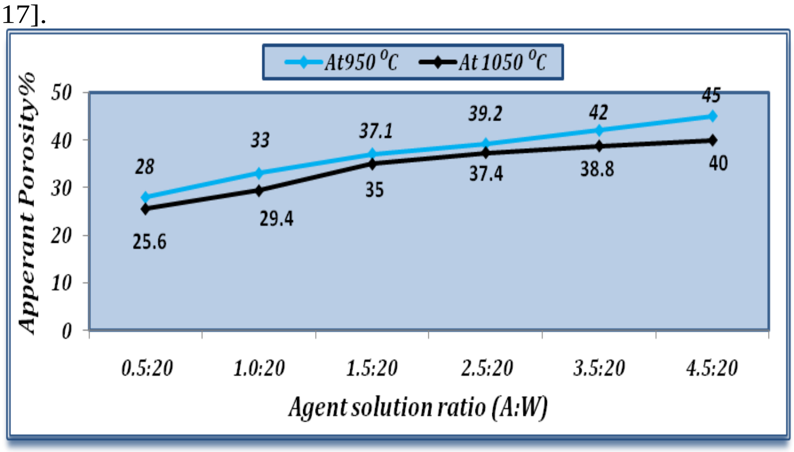


Fig. (6). Effect of foam solution ratio on Apparent Porosity.

4.2.2. Thermal conductivity

Thermal conductivity is the most important factor influencing the apparent porosity is, high porosity resulting in low thermal conductivity, previously reportedby Shihab Zaidan (2017) as shown in Fig. (7). This porosity act as a barrier to the heat flow.

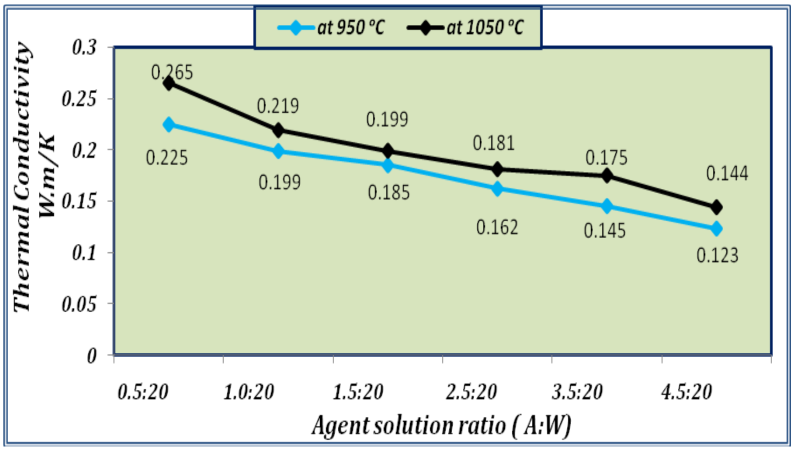


Fig. (7). Effect of foam solution ratio on Thermal Conductivity.

4.2.3. Compressive strength

Thus, compressive strength dramatically decreased with increasing addition of foam agent, the compressive strength of foam brick decreases from (9-4.9) MPa for foam brick firing at 95°C and (10-5.5)MP for foam brick firing at 1050°C, with the increase in foam agent to water from 0.5:20 to 3.5:20 as shown in Fig. (8). An implication is that compression strength strongly depends on the apparent porosity, Wan Ibrahim1 et al. (2017) inferred that the compression strength of foam ceramic related to its porosity. But the increasing of firing temperature from (950, 1050)ºC results decrees in apparent porosity and increase in thermal conductivity and compressive strength this result agreement with research [12] also reported that the curing temperature influenced the strength.

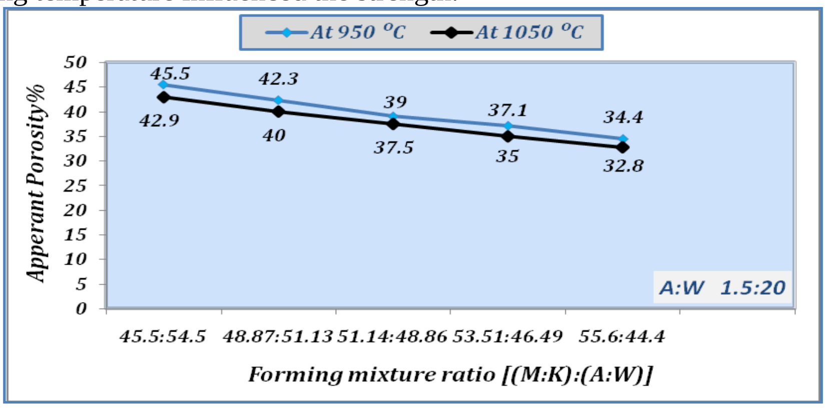


Fig. (8). Effect of agent solution ratio on Compressive

Through the previous test apparent porosity ,thermal conductivity and compression strength ,it was found the two ratio 1.5:20 and 2.5 :20 of foam agent : water is represent the best ratios for manufacturing foam brick for this select and independent when change another variables.

4.3. Stage 3

From stage 1 the ratio (60:40) of Mullite :kaolin and from stage 2 the ratios 1.5 :20 & 2.5:20 of foam agent : water has identified optimum ratios for making foam brick respectively to have high apparent porosity , low thermal conductivity and acceptable value of compressive strength. Then these ratios independent to study the effect parameter forming mixture, clay mixture : agent solution on versus apparent porosity, thermal conductivity and compressive strength respectively as shown in Figs. (9-15) for foam brick firing at (950, 1050)ºC.

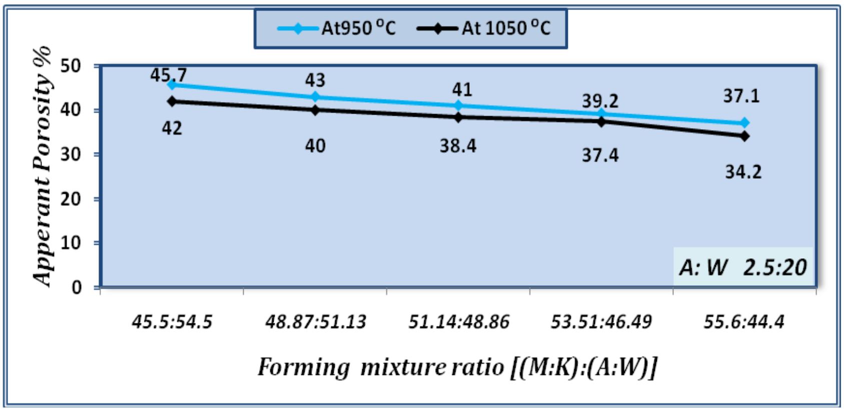


Fig. (9). Effect of forming mixture ratio on Apparent Porosity.

4.3.1. Apparent porosity

From Figs. (9 and 12) it can be seen decrease in apparent porosity with increasing clay mixture amount, and that is a result to the increment of ceramic material, that is, to increase the structure of mullite phase and liquid phase at the expense of porous phase, the decrease of pores in the mixture, mainly due to the decrease of solution of foam agent relative to clay mixture which is originally release bubble to during forming process and remaining materials burning through firing process, Both are responsible for generating the bubbles which produced porosity.

4.3.2. Thermal conductivity

For the porosity decreased thermal conductivity increases for it related to the porosity ratio, porous volume and shape of pores, Johnson (2018) written lower porosity means Higher thermal conductivity of material However it has been known (in this study) that the thermal conductivity tends to decrease with the increases in clay mixture amount as shown in Figs. (10 and 13).

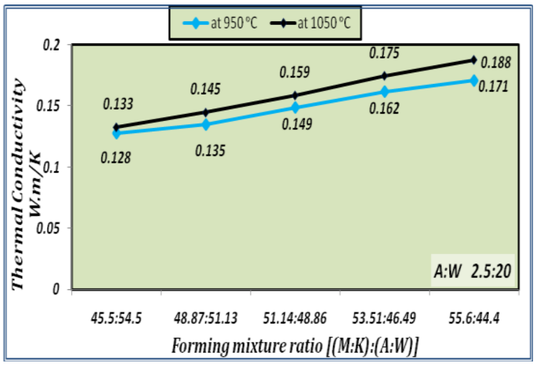


Fig. (10). Effect of forming mixture ratio on Thermal Conductivity.

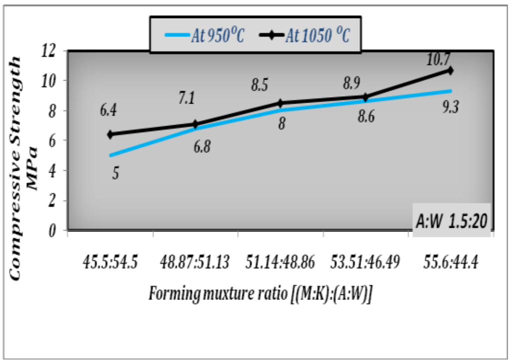


Fig. (11). Effect of forming mixture ratio on Compressive strength.

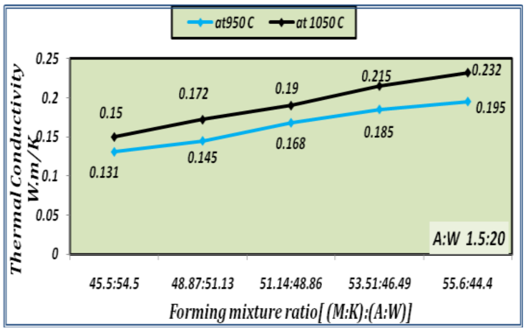


Fig. (12). Effect of forming mixture ratio on Apparent Porosity.

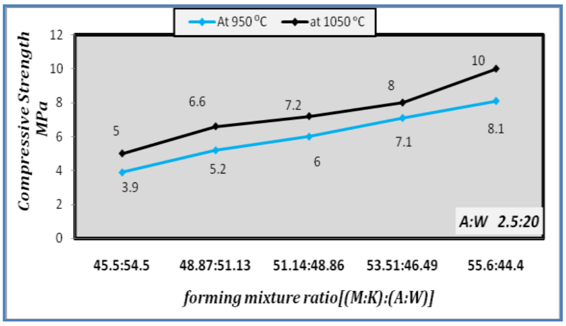
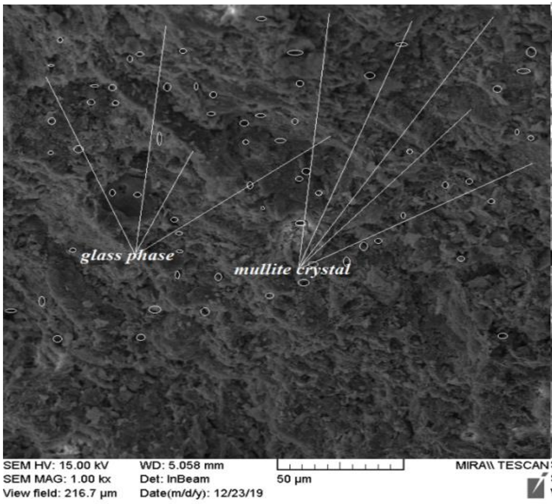


Fig. (13). Effect of forming mixture ratio on Thermal Conductivity.

Image 1,a : sem image of foam brick with ratio Image 1,b : sem image of foam brick with ratio 1.5:20 In magnification 10.00kx 1.5:20 In magnification 1.00kx



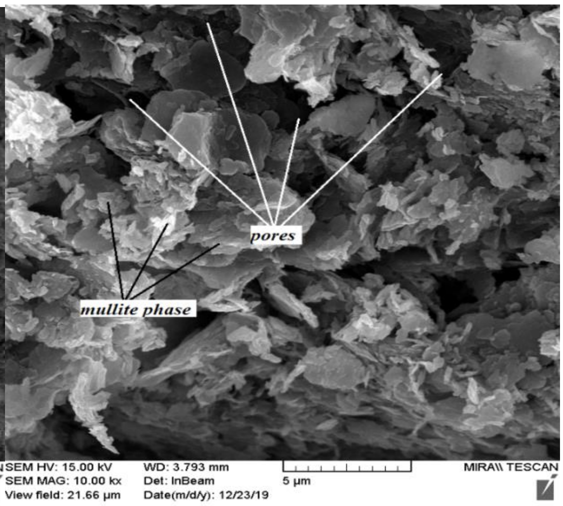
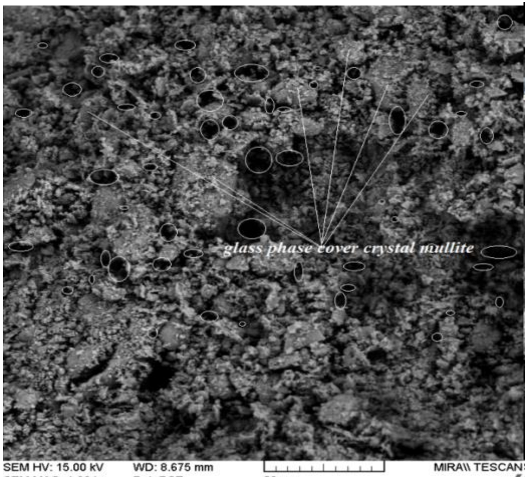


Image 1,a : sem image of foam brick with ratio 2.5:20 In magnification 1.00kx

Image 1,b : sem image of foam brick with ratio 2.5:20 In magnification 10.00kx



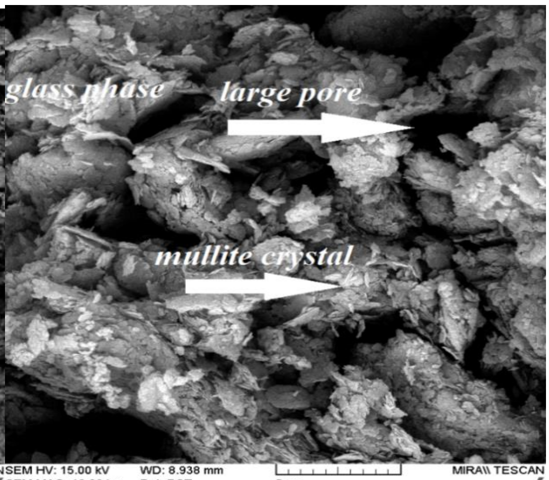


Image 2 ,a : sem image of foam brick with ratio 2.5:20In magnification 1.00kx

Image 2,b : sem image of foam brick with ratio 2.5:20In magnification 10.00kx

Fig. (14). Effect of forming mixture ratio on Compressive strength.

4.3.3. Compressive strength

The compressive strength is inversely commensurate to the porosity and this reason explains why the compressive strength grows with increase clay mixture ratio as shown in Figs. (11 and 14)for to increase Mullite phase .when the firing temperature rise from (950,1050)ºC porosity decreased for all mixture ,this can be attributed to the decreasing micro pores that occurred due to the densification and this lead to increase in thermal conductivity and compressive strength as explained earlier.

Through the previous test apparent porosity, thermal conductivity and compression strength ,it was found the ratio 51.14 % of clay mixture is represent the best ratio for manufacturing foam brick for having the best value of apparent porosity, thermal conductivity and acceptable value of compression strength.

4.3.4. Microscopic structure

The images 1 (a, b) and 2 (a, b) show the microstructure of the fracture surface for optimum foam brick prepare for two ratio (1.5:20) & (2.5:20) with two magnification1.00 kx and 10.00 kx respectively .

From the images notice there are a number of isolated and separated pores that represent the porous phase in addition to the presence of mullite crystals, which represent the mullite phase, as well as we notice the glass phase but when comparing the two image, notice that the size of the pores is larger and the number is more in the image 2, and also that the percentage of mullite crystals is less and the glass phase is relatively few for increase agent solution ratio mean increasing the ratio of pores volatilized causing the formation more bubbles during the forming process this agreement with porosity results and the greater percentage of pores, the less the proportion of the glass phase [18].

Fig. (15). show the specimens of foam.

5. Conclusion

The optimum products foam brick obtained with 20:80 clay mixture ratio, 1.5:20 & 2.5:20 respectively agent solution ratio and (51.14:48.86) forming mixture ratio. This foam brick characterized with apparent porosity (39, 41) respectively. It has a compressive strength of (8, 6) MPa, respectively and thermal conductivity (0.168, 0.149) K/W. m.

On the basis of the experimental work it is concluded that apparent porosity increased with boosted Mullite phase ratio, but compression strength and thermal conductivity decreased. It is also analyzed increased with increased foam agent ratio for more bubble form during work process this lead increased in apparent porosity and compression strength and thermal conductivity decreased with increased foam agent ratio which are independent on porosity. The firing temperature is a function of porosity when firing temperature increased apparent porosity decreased. The samples prepared in present work shows promise light weight and thermal insulator material used in construction application.

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