ASSESSMENT OF USING A NEW EGYPTIAN FLUXING MATERIAL FOR CERAMIC TILES PRODUCTION.

Mohamed M. EL-Sayed Seleman [a],
Neven Ali [b] , ***Magdy S. Basta*** [b] , ***Farouk A. Mohamed*** [c]

ABSTRACT

During the last two decades, the demand for ceramic tiles has increased specifically in developed countries, therefore, the installation of new ceramic factories becomes vital, and consequently, the need for ceramic products based on local new materials with specific characteristics has increased. The present study deals with the use of new fluxing material in designing tile bodies. Clay raw materials from Sinai and Aswan representing kaolin and Ball clay, namely as El-Teeh and Abu Sbeira areas, respectively were utilized with percentage equals to 50 %. Albitite from Sinai and albite from Turkey were separately used with El-Teeh clay and with Ball clay with percentage equals to 25%. White sand from Zafarana was used with the four mixes with percentage equals to 25%. The raw materials were crushed, milled, mixed, and pressed at forming pressure of 50 MPa. The green compacts were finally dried at 110ºC and then fired at temperatures in the range from 1100 ºC to 1250 ºC at a constant rate of 5 ºC/min for 60 min soaking time. Physical and thermal properties of the produced specimens were measured. The obtained results from the ceramic parameters of the tile bodies indicated that using either local Egyptian albitite or Turkish albite with El-Teeh clay gave non porous tile bodies which having no water absorption and high bulk density of 2.95 gm/cm^3 for Egyptian albitite and 2.72 gm/cm^3 for Turkish albite when both products heated at 1200 ºC. Furthermore, blending the Egyptian albitite and the Turkish albite with Ball clay and firing at 1225 ºC gave tile bodies characterized by water absorption of 0.6 % and 1.3 %, apparent porosity of 1.56 % and 3.31 % and bulk density of 2.60 gm/cm^3 and 2.55 gm/cm^3, respectively. Thus, the processing route with the suggested mixtures could produce heavy duty tiles. Finally, based on the obtained results, it can be recommended that the use of local Egyptian albitite instead of Turkish albite in ceramic tiles production is practical and advised for industrial utilization.

KEY WORDS: Ceramic tiles, Ball clay, Kaolin, Albitite, Albite, water absorption, Bulk density, Shrinkage

زاد الطلب على البلاط الخزفي أثناء العقدين الأخيرين وبشكل خاص في البلاد المتقدمة، لذا فإن إنشاء مصانع جديدة أصبح أمرا حيويا، ومن ثم فإنه زاد الإحتياج إلى خامات مصرية محلية جديدة لها مواصفات وخصائص تكنولوجية مواكبة لهذا الطلب. لهذا تهدف الدراسة الحالية إلى إستعمال مواد مصهرة جديدة والتى هى من أساس مكونات خلطة البلاط الخزفى . (متمثلة فى استخدام الألباتيت (Albitite) المصرى المحلى بديلا عن الألبيت (Albite) التركى المستورد) ولتحقيق هذا الهدف تم تحضير أربع خلطات مختلفة إعتمادا على نوعين من الطفلة أحدهما من منطقة التية - بشبه جزيرة سيناء وهى المتمثلة فى الكاولين (Kaolin) و الأخرى من منطقة خور أبوصبيرة بأسوان وهى متمثلة فى البولكلاى (Ball Clay) وكانت نسبة الكاولين 50 % بالوزن فى الخلطة الاولى والثانية والبولكلاى 50 % بالوزن فى الخلطة الثالثة والرابعة وتم إضافة الألبيت التركى إلى الخلطة الأولى والثالثة بنسبة 25 % بالوزن وأضيف الألباتيت المصرى المستخرج من سيناء

a) Department of Materials and Metallurgical Eng., Faculty of Petroleum and Mining Eng., 43721, Suez, Egypt. (Corresponding author : Mohamed. M. EL-Sayed Seleman (mmelnagar@yahoo.com)
b) Department of Basic Science and Mathematics, FPME, Suez Canal University and
c) Department of Geology, Faculty of Science, Suez Canal University, Ismailya, Egypt.

إلى الخلطة الثانية والرابعة بذات النسبة وذلك بهدف المقارنة وإضيف الرمل الأبيض من منطقة الزعفرانة بنسبة 25 % إلى جميع الخلطات الأربعة. والخامات المستخدمة تم تكسيرها وطحنها وخلطها ثم شكلت تحت ضغط 50 ميجابسكال إلى عينات إسطوانية ذات قطر 2.5 سم وارتفاع 0.3 سم وتم تجفيف العينات الخضراء عند درجة حرارة 110 م^{o} ثم تم حرقها عند درجات حرارة مختلفة من 1100 م^{o} إلى 1250 م^{o} وبمعدل ثابت 5 م^{o} / دقيقة لمدة ساعة ولقد تم تعيين الخواص الطبيعية للعينات المحروقة و شملت الكثافة النوعية وامتصاص الماء و المسامية الظاهرية في درجات الحرارة المختلفة و أمكن تحديد درجة حرارة النضج لكل خلطة وتم عندها التعرف علي التركيب الطورى للعينات المحروقة وذلك بلستخدام الأشعة السينية حيث أمكن متابعة كميات الأطوار المختلفة لكل خلطة و كذلك استخدم الميكروسكوب الماسح (SEM) للتعرف علي البنية المجهرية. ولقد أظهرت النتائج فى الخلطة الأولى والثانية التي تحوي طفلة التيه أن انسب درجة حرارة لنضج للعينات كانت 1200م^{o} حيث أعطت عينات درجة إمتصاصها للمياة قد تصل إلى الصفر و الكثافة الكلية كانت عالية علما بأن الكثافة في العينات المحتوية على الألباتيت المصري (2.95 جم/سم^{3}) أعلى قليلا منها في وجود الألبيت التركي (2.72 جم/سم^{3}) . بينما في الخلطة الثالثة والرابعة والتي تحوي البولكلاى أن انسب درجة حرارة لنضج العينات هي 1225م^{o} حيث أوضحت النتائج أن العينات التي تحوي الألباتيت المصري لها أقل إمتصاص للماء (0.6 %) ومسامية 1.56 % وكثافة كلية 2.65 % علما بـأن مثيلاتها في وجود الألبيت التركي كانت 1.3 % و 3.31 % و 2.55 % على الترتيب. ومن ثم فإن الألباتيت المصري مرشح بقوة بديلا عن الألبيت التركي فى إنتاج البلاط الخزفى المصرى.

1. Introduction:

Ceramic industries are vital and necessary in the human life. Ceramic products are diversified such as tiles of all types, porcelain, tableware, bricks, chinaware, all types of glass, sanitary ware, etc. Moreover, ceramic products can be divided into those used at normal and high temperatures. These divisions can also be subdivided into porous and nonporous products [1,2]. The properties of the produced ceramic bodies depend mainly on the particle size, types, purity, relative amounts of raw materials [3-10]. Furthermore methods and conditions used in the manufacturing processes are very effective [11-14].

The previous studies on the ceramic industries and processing are diversified, it was reported that feldspars are widely used in the fields of tile, glass and sanitary equipment than other minerals [15-16]. Natural raw materials such as granite, basalt, pegmatite, phonolite, nepheline syenite and perlite are widely used in ceramic industries as fluxing materials [17-19] showed that the Argentinian kaolins can be used as ceramic raw materials and considered them as stoneware clays. They also mentioned that when kaolin with lower iron oxide content are mixed with quartz and feldspar, good white stoneware would be obtained at firing temperature of 1150 ºC.

The feldspar raw materials in silicate ceramics bodies and their different effects on sintering behavior during formation were discussed [16, 20]. Kobayashi et al, [3] studied the effect of the particle size of the raw materials on densification and bending strength of porcelain bodies in quartz- feldspar-kaolin system. They found that when feldspar powders of 1.2 μm in particle size were used, the porcelain bodies were fully sintered at about 1175 ºC and maximum bending strength of 176 MPa was obtained. Swapan and Kausic [21] studied porcelain bodies fabricated from triaxial mixtures of clay, quartz and feldspar which having different amounts of Na_2O and K_2O. Their studies investigated the densification behavior on thermal treatment at which the bodies achieve full vitrification. The degree of vitrification of the densified samples that were heated at different temperatures was determined by measuring the shrinkage, bulk density, percent of water absorption and flexural strength. They found that, the Na-rich feldspar containing body composition achieves full vitrification at lower temperature compared with the K-rich feldspar.

Ceramic wall and floor tiles are considered as building materials which are designed for the use as floor and wall covering either indoors and/or outdoors regardless of their shape or size. Tiles can classified according to the degree of water absorption into low, medium and

high water absorption. Floor tiles are dense, fully vitrified smoothed colored bodies which are produced with different dimensions and with about 1.1 cm thickness. Their colors and textures can be achieved with the use of some additives. Their water absorption should not exceed 6 %. They generally exhibit high resistance to abrasion, wear, stains etc. Wall tiles, on the other hand, are porous bodies with different dimensions and have a thickness of about 0.6 cm, white or colored, glossy or matt glazed and have water absorption more than 10 %. Among the various types of ceramic floor and wall tile, porcelain tile is the product which in recent years has shown the greatest rate of increase (on a percent basis) in the amount produced, amount sold, and obviously amount used [22]. The American National standard Specifications for ceramic Tile defines porcelain tiles as: dense, smooth, impervious (with water absorption of 0.5 percent or less), and stain resistant [23].

Ceramic tiles production has shown a great rate of increase in recent years. In Egypt, tile production was 20 million m^2 in 1996, while it reached 83 million m^2 in 2004 with an increase of more than four folds (> 400 %). In 2006, the production of Egyptian factories was about 100 million m^2 [13]. So obtaining cheap and durable products manufactured from Egyptian the local raw materials would be necessary.

In Egypt, there are several factories that produce ceramic wall, floor and porcelain tiles. They mainly use imported raw materials and a little portion of Egyptian raw materials. Consequently the aim of this work is to use Egyptian raw materials in order to produce different types of tiles that satisfied the level required by the standards.

2. Ceramic Raw Materials

The ceramic industry depends essentially on common minerals such as clays, quartz and feldspars, producing whiteware and porcelain. These raw materials are frequently classified according to their function in the body as clays, filler (quartz) and flux (feldspar), however recently there is growing need for uses more suitable low cost fluxes, especially those of low temperature vitrification mixes.

Clays are the most widespread and easiest minerals adequate utilized by human. They are earthy substances consisting chiefly of hydrous aluminum silicates. Clays are the major raw material providing the desired plasticity for shaping and forming processes of ceramics.

In fact, the use of quartz in the ceramic industry far exceeds the need of filler. It actually develops a highly viscous glassy phase that prevents the collapse of the body as vitrification starts. It is also responsible for the development of the ceramic bond that forms as this liquid slowly fills the pores and the body cools down and decreases drying shrinkage when plastic forming is used.

Feldspars are used in ceramics for making glass and pottery in both body of the ware and the glaze, since they are the main source of the alkali metals (Na and K), which act as flux materials. They reduce firing temperatures and improves the strength of ceramic body by assisting glass formation. Feldspar lightens the body if fired below 1100 ºC and causes considerable shrinkage of the body in the temperature range between 1140 ºC to 1350 ºC. This is due to vitrification and fusion. Potassium feldspar lowers the thermal shrinkage whereas sodium feldspar lowers thermal expansion. Albite is particularly used in the ceramic and glass industries because it fuses at lower temperatures than most of the other ingredients, and as a result, it cements the crystalline phases in some types of ceramic bodies.

The aim of the present work is to study a new feldspar source from Wadi Remthi, South Sinai and its effect with two types of clays (El-Teeh clay from Sinai and Ball clay from Aswan) on the production of ceramic tiles. The present study includes three main parts:

1- Determination of the thermal behavior of green bodies to throw light on the different reactions taking place during firing.
2- Determination of Physical properties which include firing shrinkage, apparent porosity, bulk density and water absorption. These tests would give an idea about the maturing temperature of each mix.
3- Determination of phase composition of the produced bodies by X-ray diffraction analysis and assessing the texture and structural changes occurring after firing by using scanning electron microscope.

3. Experimental Procedures

Several techniques on both the raw materials and the produced ceramic bodies are used. These methods include the selection and the assessment of the raw materials, testing and measuring techniques for ceramic parameters.

3.1. Raw materials preparation.

From each raw material of the base composition, about 15 Kg were provided in the form of lumps. Rock samples of albitite were collected from Wadi Remthi. The selected samples were crushed using a roller crusher. The size of original rock particles was between 2 -3 cm, after crushing the size was reduced to attain 2-3 mm. The starting materials were also ground. All powders were screened to pass 200 mech. The fine powders were then mixed according to the designed proportions.

3.2. X- ray diffraction (XRD) analysis:

A Phillips X-ray diffractometer model PW/1710 with Cu Kα radiation (λ=1.5405 A°) tube and Ni–filter at operating conditions was used for the rapid qualitative identification of the mineralogical constituents of the studied samples. The specimens were prepared by pealing the fine grained powder into the conventional diffractometer sample holder in the X-ray unit. The obtained diffraction charts and the relative intensities were correlated to the ASTM X-ray diffraction line index. In the differctogram, for each line the 2θ and the absolute intensity are listed as well as the d (A°) and the relative intensities are calculated. Matching of *d* and $1/1_0$ of the diffractogram with that of the standard ASTM cards gives the qualitative identification.

3.3. Grinding schedule:

Grinding of the crushed samples was carried out using a porcelain ball mill. Two methods of grinding were used; dry and wet with distilled water .The grinding for the two systems were carried out with the same ratio of powder to balls which was 1:5.

3.4. Choice and assessment of raw materials:

The chosen raw materials were previously mentioned at the present introduction. All of them were separately ground then mixed in the proper composition in weight percentage. The raw materials were mixed as fine powders by the quartering method. Four basic mixes were prepared by subjecting the ground materials to wet mixing for one hour then the mixes were left at 110 ºC till complete dryness.

3.5. Particle size analysis:

In the present work, the particle size analysis was determined using mechanical sieve analysis. A nest of sieves: 200, 160, 125, 90, and 63 μm was used. The quality of particle size separation was checked using a Shimaduze SALD- 2100 model laser diffraction particle size analyzer.

3.6. Differential thermal analysis (DTA):

The thermal stability of raw materials was monitored with differential thermal analysis (DTA), Perkin-Elmer DTA7 (computer controlled) used for the characterization and analysis of the thermal properties of the materials. Alumina calcined at 1200 ºC was used as reference inert substance. The sample was heated up to 1100 ºC with a constant rate of 15 ºC /min.

3.7. Compacting processing:

The powders were compacted in a single acting die-set having 2.5 cm internal diameter. Oil was applied on the inner surface of the container and the outer surface of the punches as lubricant in order to minimize the friction forces. The die was carefully cleaned at the beginning of each compaction process and lubricated again. The compaction process was carried out using Universal Instron Machine with maximum load of 300 KN, Model 4208 at constant punch traveling speed of 1 mm/min. The required specimens were formed as discs (2.5 cm diameter and 0.3 cm thickness). It was preferable to use a constant weight of powder for each specimen. The prepared specimens were dried for 48 hours in air followed by 24 hours at 110 ºC in an electric oven before firing.

3.8. Firing technique:

Firing temperatures and firing times are the principal factors controlling the firing process. The firing temperature was varied between 1100 and 1250 ºC. The temperature was raised at a rate of 5 ºC/min followed by soaking period for 1 hour at maximum firing temperature, then left to cool down to room temperature. Firing was carried out using an electrical muffle furnace.

3.9. Physical properties:

Determination of water absorption, bulk density and apparent porosity

The studied fired discs for each sample were individually tested and their results were calculated according to the following procedures (ASTM, Designation: C. 373-72, Reapproved 1982). Discs were immersed in water, boiled for 2 hour to get rid of all air bubbles and released from the specimen. After being cooled, the sample was weighted soaked with water (W_W). The sample was slowly suspended in water (W_S), followed by the weight of the sample after drying at 110 ºC for 24 hours (W_D). So, the following important three physical properties were calculated from the following relations:-

$$\text{Water absorption} = \frac{W_W - W_D}{W_D} \times 100\ \%$$

$$\text{Bulk Density} = \frac{W_D}{W_W - W_S}\ \text{g/cm}^3$$

$$\text{Apparent porosity} = \frac{W_W - W_D}{W_W - W_S} \times 100\ \%$$

According to these data the respective maturing temperatures of each mix were determined.

3.10. Microstructure of fired bodies:

Microstructure and pore size distribution were studied by scanning electron microscope (SEM) model Phillips XL 30. The electron microscope makes use of directing a finally focused beam of primary electron accelerated under a maximum potential difference of 30-50 K.V., magnification 10 x up to 400.000 x and resolution for W.(3.5 nm), to scan on the specimen surface. A picture of the surface of the specimen is developed and can be displayed on the screen of a cathode tube. The specimens fired at the optimum conditions were polished on the plan surface with carborundum paper of different grades 300, 600 and 1000. The specimens were then washed in an ultrasonic bath for half an hour. The polished specimens were subjected to etching by 20% hydrofluoric acid solution, for 30 seconds then washed in the usual way. After that they were coated with a thin layer of gold 200-300 A° using a sputtering apparatus, and the time needed was 5 minutes.

4. Results and Discussion

Processing Techniques:

4.1 Grinding:

In the present study, the specimens were crushed using a roll-crusher to reduce the grain size to a range of 2-3 mm. Grinding was performed using a porcelain ball mill with constant ratio of the weight of the powder to balls 1:5 in all specimens. Two methods of grinding were used namely; dry and wet methods. In the first, 200 gm of powder and 1000 gm of balls were charged in the porcelain jar at time intervals of 180, 360 and 540 min. After each time, the milling product is sieved to determine its grain size. In the second method, the jar is always charged with 200 gm of powder and 150 ml of distilled water in which they are subjected to hand mixing then the balls were placed in the jar. The time intervals were 45, 90, 145 and 180 min. After each time period, the milling product was subjected to sieve analysis.

4.2. Raw materials for tile bodies

In the present study, local Egyptian raw materials were used namely, Ball clay from Abu Sbeira gully, (North Aswan), El-Teeh clay (Sinai), Zafarana white sand (Northeastern, Eastern Desert of Egypt), Remthi albitite (South Sinai) after milling and Turkish albite (Kirsehir, Turkey). The chemical analyses of these raw materials are listed in Table 1. El-Teeh clay is massive, very white in color, highly plastic in nature with kaolinite minerals as the main clay mineral present and it is considered as flint clay.

Ball clay was first introduced in the tile production in Egypt in 1967, and is still being used till now due to its excellent pressing properties and high economic potentiality. In addition, due to its negatively high Fe_2O_3 content (up to7 %), it imparts an off-white color

after firing to the tested tile bodies. Ball clay is characterized by fine particle which was reflected also on the values of both plasticity and flexural strength of the tile mixes.

White Sand (Malha Formations, Zafarana area) is characterized by white color, moderately to well sorted, rounded to well rounded, semi consolidated to friable and medium sand size [24]. Turkish albite from Kirsehir area (about 150 km Southeast of Ankara) is very white in color; it was used after milling. The quarry under the auspices of Essan Co.(Istanbul, Turkey).

Table 1 Chemical composition of the starting raw materials (in wt. %)

Material / Component	El-Teeh Clay	Ball Clay	Remthi Albitite	Turkish Albite
SiO_2	44.70	53.77	55.30	69.67
Al_2O_3	37.15	25.92	26.80	19.70
TiO_2	1.80	1.49	0.90	0.05
Fe_2O_3	0.83	7.04	0.04	0.14
CaO	0.75	0.74	7.60	0.97
MgO	0.52	0.30	N.D.	0.05
K_2O	1.05	0.93	0.32	0.25
Na_2O	0.72	0.42	6.20	11.20
MnO	N.D.	N.D.	0.003	N.D.
Cl	0.03	N.D.	N.D.	N.D.
SO_4	0.52	N.D.	N.D.	N.D.
LOI	13.01	9.36	0.80	0.17
H_2O	N.D.	N.D.	0.167	N.D.

∗The average silica content in the White sand samples are between 98.5 - 99%.
∗N.D. =Not Detected.

4. 3. Results of grindability and particle size analysis

The results of the particle size analysis of the albitite after every milling time are shown in Tables 2 and 3.

Table 2 Particle size analysis of albitite using dry milling method

Particle Size (μm)	Weight fraction (w/w_o)		
Grinding time (min)	180	360	540
200	0.18059	0.101051	0.074575
160	0.030015	0.041521	0
125	0.07904	0.026013	0
90	0.057529	0	0
Less than 90	0.652826	0.831416	0.925425

Table 3 Particle size analysis of albitite using wet milling method.

Particle Size (µm)	Weight fraction (w/w_o)			
Grinding Time (min)	45	90	145	180
200	0.242192	0.160663	0.116034	0.082292
160	0.044547	0.015839	0	0
125	0.06042	0.031573	0	0
90	0.051203	0.040373	0.030063	0
Less than 90	0.601639	0.751553	0.853903	0.917708

The final milled product which has passed through the 90 µm mesh sieve was checked using laser diffraction particle size analyzer to determine its actual particle size distribution. The data obtained are graphically represented in Figs. 1 and 2.

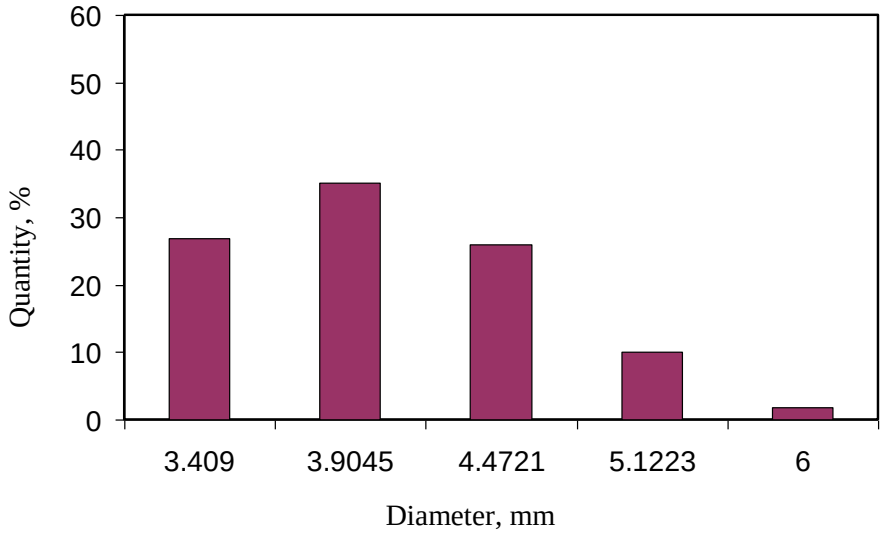

Fig.1. Graphical plotting of grain size analysis for albitite after the dry milling.

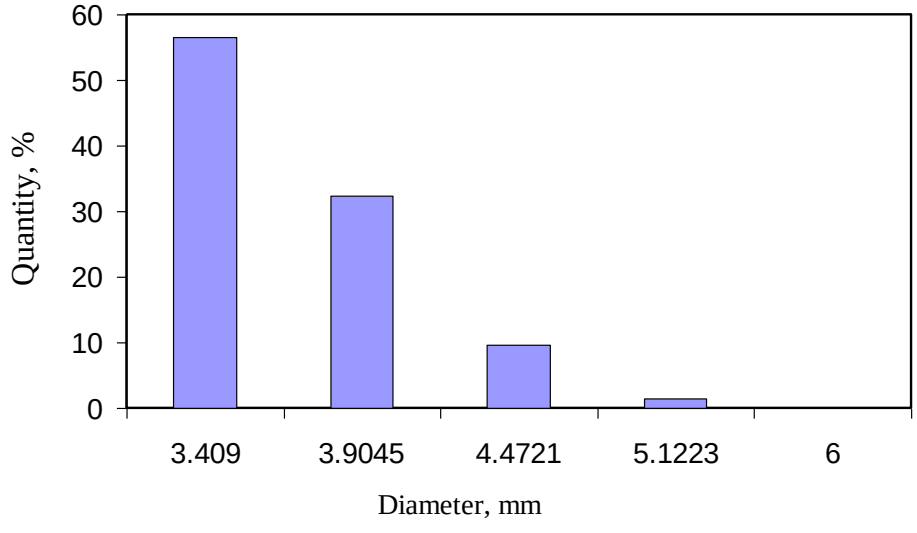

Fig.2. Graphical plotting of grain size analysis for albitite after the wet milling.

4.4. Effect of firing rate on the raw materials:

The effect of firing rate on the dissociation of kaolin which is the main component in ceramic bodies was carried out by many researchers [1,25]. They found that, increasing the firing rate to 30 ºC /min resulted in a shift in the peak area of the D.T.A curves of both endothermic and exothermic reactions. Thus, the endothermic reaction is displaced up to 170 ºC and the peak area is 22.8 times that fired by a rate of 2 ºC /min. Meanwhile, the exothermic reaction has a peak area being 15 times and a shift of 80 ºC for the same conditions.

The endothermic reaction accompanying the (low-high) temperature forms of quartz transformation, takes place suddenly and in a very short temperature interval but at the same temperature of slow rates, i.e the heating speed has no influence on the grade or intensity of this thermic reaction [26].

4.5. Differential thermal analysis

The considered samples were heated up to 1100 ºC at a constant rate of 15 ºC /min and the obtained DTA curves are given in Fig.3. The DTA curves of the clay as indicated in Figs.3-a and 3-b show that the first endothermic peak was occurring at temperature between 110 ºC and 140 ºC as a result of the loss of hygroscopic water. The second endothermic peak occurs at 550-580 ºC represents the absorption of heat due to the break down of the clay mineral structure attained when the clay mineral loses the combined water. An exothermic peak also appears at 970 - 975 ºC accompanied by the evolution of heat due to the formation of spinel phase. Figs.3-c and 3-d show the DTA curves of albitite and albite, respectively. As it is clear from both Figs 3-c and 3-d there is only one endothermic peak at 120 ºC and 140 ºC as a result of the loss of hygroscopic water. An endothermic peak at 573 ºC was observed in white sand, as shown in Fig.3-e. This endothermic peak is due to the inversion of α-quartz to β- quartz.

4. 6. X- Ray diffraction (XRD) analysis

From the corresponding XRD graphs of El-Teeh and Ball clay (Fig.4), the distinctive presence of kaolinite and illite shows as main mineral phases. Furthermore, quartz is also detected. it can be concluded, that the kaolinite and illite are presented as main mineral phases. The crystalline components of the used local albitite and Turkish albite samples are shown in Fig.5. They are highly enriched in albite, anorthite and containing a cosiderable amount of quartz. Quartz is the main mineral phase detected in the used white sand sample (Fig.6).

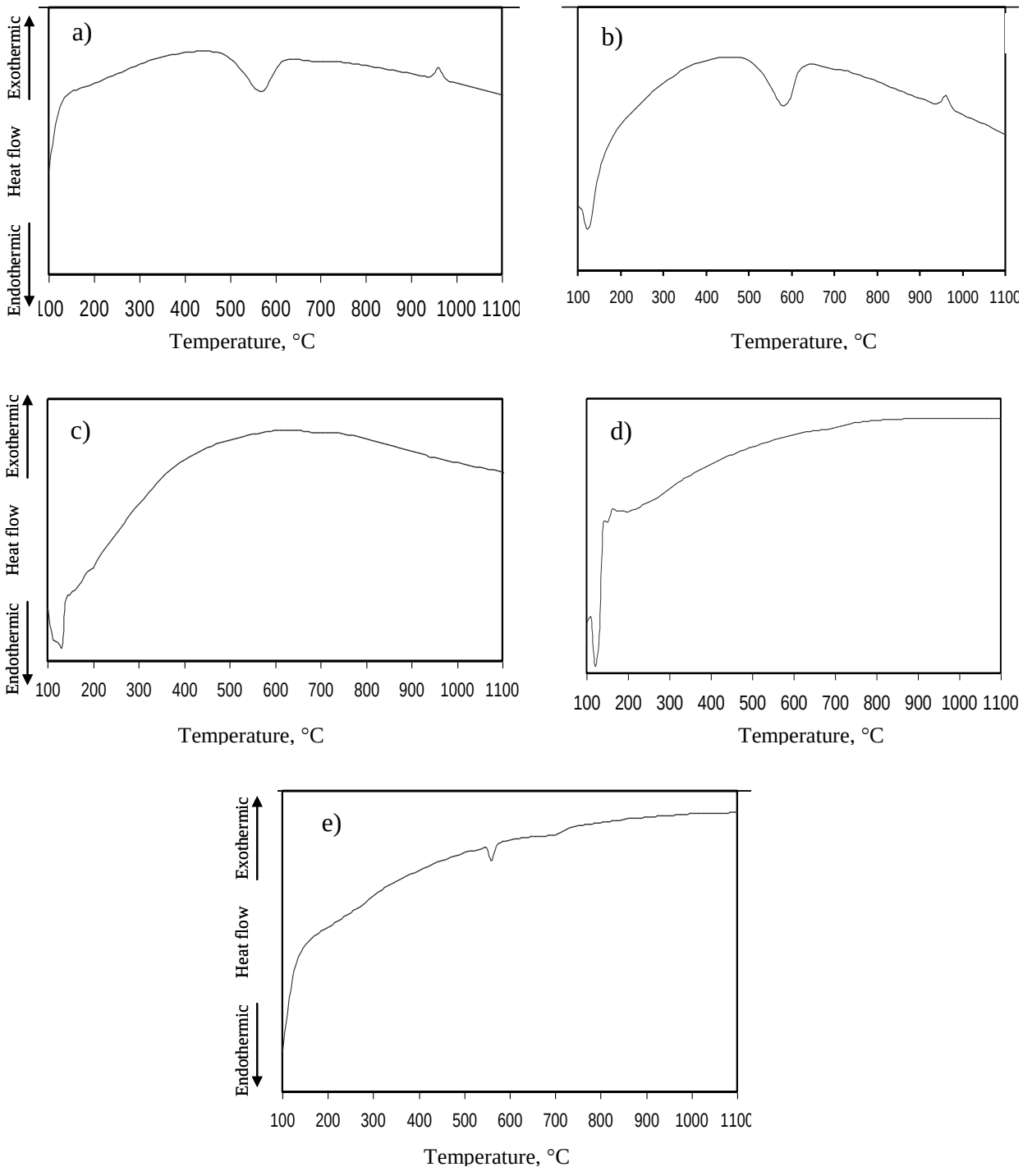

Fig.3. DTA graphically represented data for the used raw materials:

a) Teeh clay,
b) Ball clay,
c) Albitite,
d) Albite and
e) White sand.

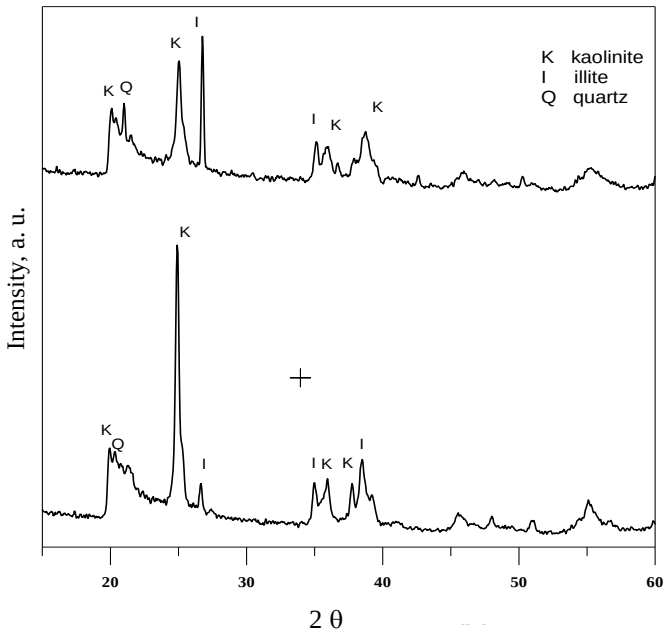

Fig.4: XRD pattern for the used El-Teeh and ball clay.

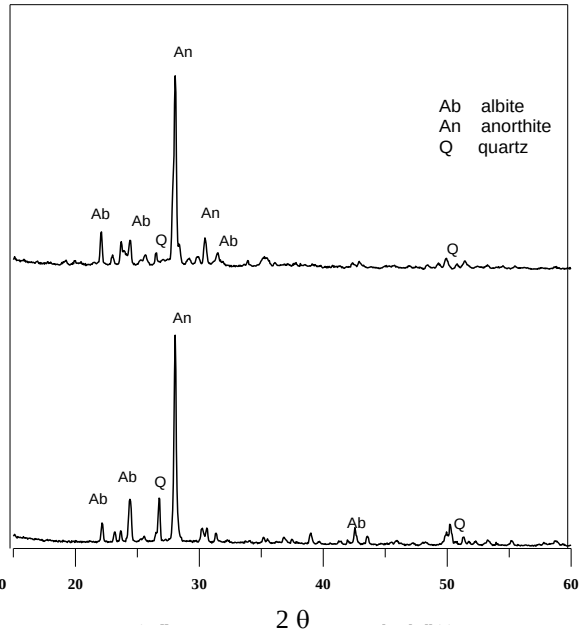

Fig.5: XRD pattern for the used Local albitite and Turkish albite.

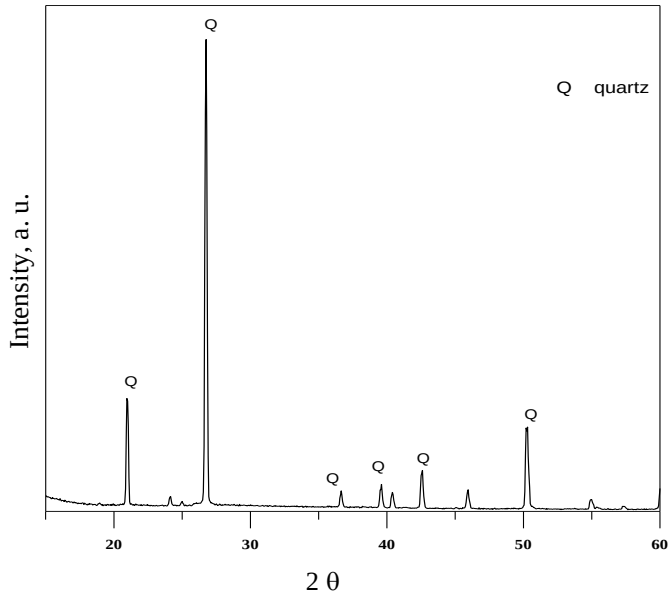

Fig.6: XRD graphically represented data for the used white sand.

4.7. Mixing

Albitite after milling was mixed with the chosen raw materials. The mixes shown in Table 4 were prepared by subjecting the ground materials to wet mixing according to weight percent of the listed constituents. The mixing was carried out in a porcelain ball mill for one hour then all mixes were left at 110 ºC till complete dryness.

Table 4 Composition of the different mixes (in wt. %)

Mix No.	El-Teeh clay	Ball clay	White sand	Turkish albite	Remthi albitite
1	50	--	25	25	--
2	50	--	25	--	25
3	--	50	25	25	--
4	--	50	25	--	25

4. 8. Pressing and Shaping

The samples for testing were prepared by dry pressing technique using the Universal Instron Machine under a pressure of 25 KN. The samples prepared to have a disc shape of 25 mm diameter and 3 mm thickness. After shaping the samples, they were dried for 24 hours in air followed by 48 hours at 110 ºC in an electrical dryer before firing.

4. 9. Sample Firing

Tested specimens were subjected to conventional firing technique whereas, temperature of the specimens was raised at a rate of 5 ºC /min, followed by soaking time for 1 hour at the maximum temperature then left to cool overnight to room temperature. The specimens were fired between 1100 ºC to 1250 ºC, with a temperature interval of 25 ºC to determine the proper maturing temperature of the corresponding interval of firing. Firing was carried out in an electrical muffle furnace equipped by automatic controller for the rate of heating.

5. Ceramic parameters:

5.1 Physical properties:

The maturing temperature for each mix was deduced from the determination of the firing shrinkage, apparent porosity, bulk density and water absorption of the fired specimens. The measurements were carried according to the ASTM standard.

5.1.1. Firing shrinkage:

The diameter of the disc specimens of each mix was measured from more than one side before firing. The mean value for each disc was represented by the symbol (Lo). Specimens were measured in the same way after firing at the respective temperature interval and the average values were designated by (L). Linear firing shrinkage was determined from the following relation:

$$S = \frac{L_o - L}{L_o} \times 100$$

The firing shrinkage values are shown in Table 5 and Figure 7.

The firing regime and type of clay and feldspar have affected to a great extent the results of physical properties are displayed by different mixes. From the results of firing shrinkage, the use of El-Teeh clay with both local albitite and Turkish albite gave gradual change in dimensions up to 1200 ºC, then the body starts to deform internally without any sign of bloating from the outside. The maturing interval is found between 1175-1200 ºC range. The use of Ball clay gave the minimum shrinkage at higher temperatures than that of El-Teeh clay. The maturing interval was found to be between 1200 - 1225 ºC. The change of feldspar has only limited influence on the firing shrinkage, Turkish albite showed the lower shrinkage values.

Table 5 Firing shrinkage (%) of different mixes

Temperature (ºC)	Mix. No.			
	1	2	3	4
1100	0	0	0	0
1150	4.2	4.6	3.1	3.7
1175	6.5	6.7	3.9	4.25
1200	6.5	6.8	3.9	4.4
1225	4.8	4.6	3.9	4.4
1250	4.7	4.4	2.7	3.5

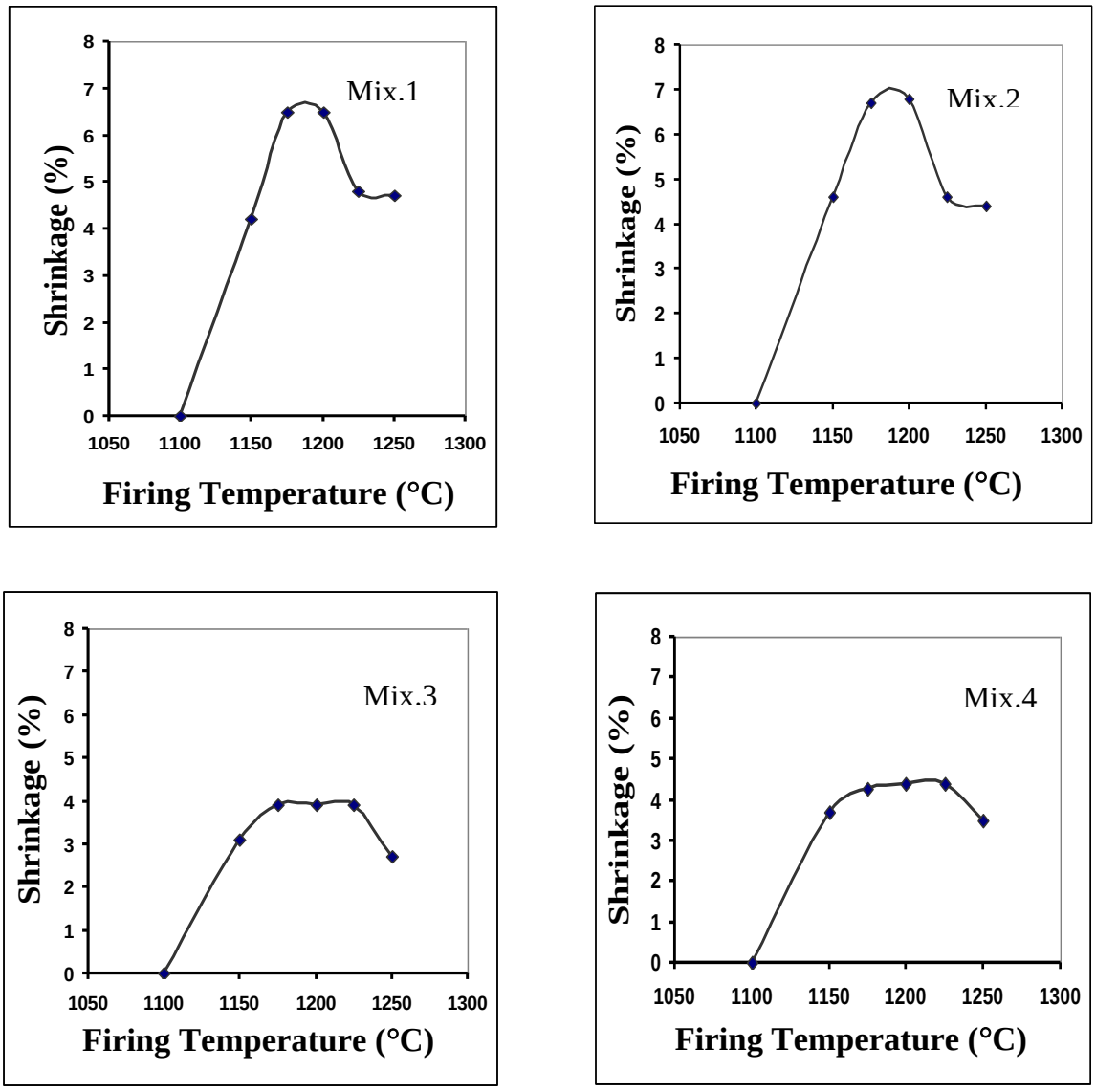

Fig. 7 Shrinkage (%) as a function of firing temperature for the different mixes

5.1. 2. Water Absorption

The results of water absorption of the disc specimens of different mixes fired at different temperatures are given in Table 6 and Fig. 8**.**

Table 6 Water absorption (%) of the different mixes

Temperature (ºC)	Mix. No.			
	1	2	3	4
1100	9.10	11.10	9.60	10.90
1150	0.75	0.41	6.10	1.57
1175	0.40	0.40	3.71	0.66
1200	0.00	0.00	2.60	0.66
1225	0.00	0.75	1.30	0.60
1250	0.10	1.20	1.70	0.64

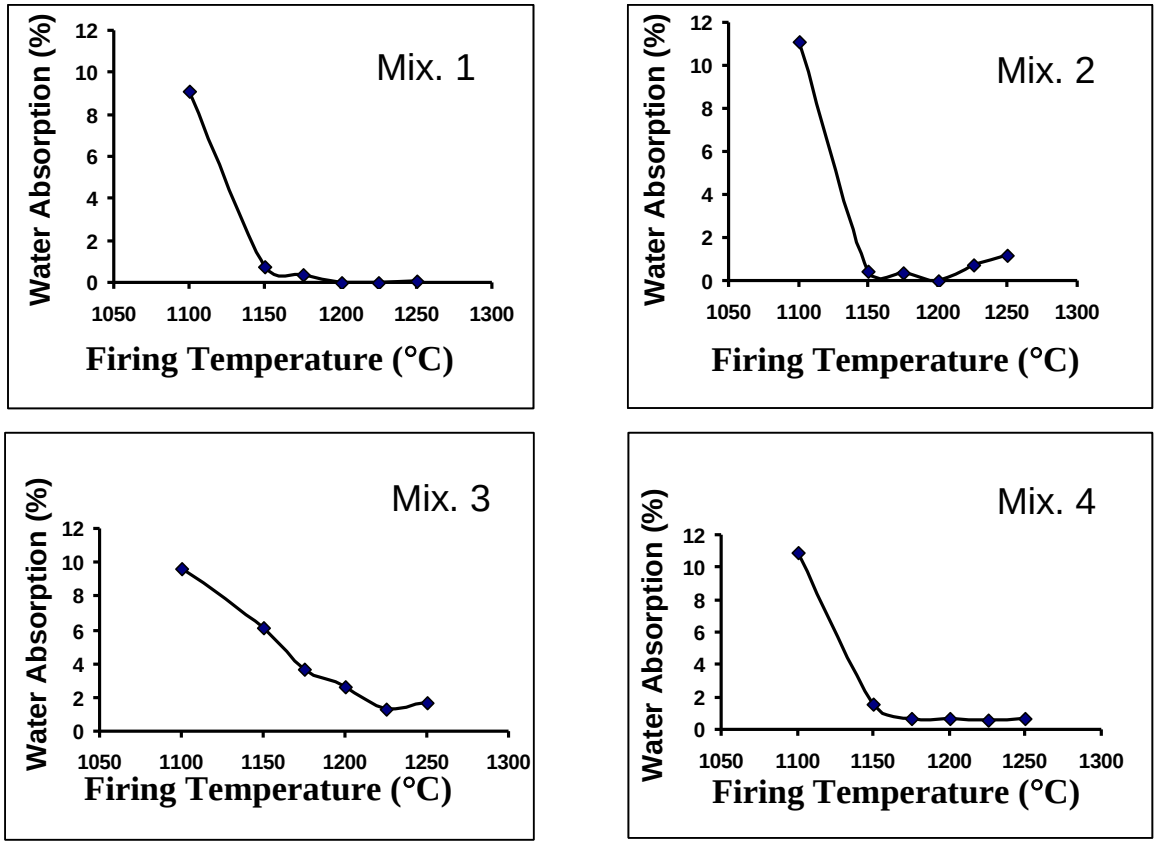

Fig. 8 Water absorption (%) as a function of firing temperature for the different mixes.

From Table 6 and Figure 8, it can be seen that the water absorption regularly decreased by rising temperature up to 1200 ºC in mixes 1 and 2 (reached to zero) and the same trend was observed up to 1225 ºC also for mixes 3 and 4. Moreover, the minimum value of water absorption of specimens containing albitite (mix.4) was 0.6 % and that of specimens containing albite (mix.3) was 1.3 %. It can be said that the surface of the fired tile bodies covered by a thin film of glassy phase at 1200-1225 ºC. Raising the temperature above this range, in which minimum water absorption was achieved, the water absorption starts to increase again but with a lower rate.

5. 1. 3. Apparent Porosity

The results of apparent porosity of the obtained fired specimen are shown in Table 7 and illustrated in Fig.9.

Table 7 Apparent porosity (%) of the different mixes.

Temperature (ºC)	Mix. No.			
	1	2	3	4
1100	21.74	23.31	18.33	21.90
1150	1.84	1.10	14.09	3.79
1175	1.00	1.08	9.10	1.66
1200	0.00	0.00	6.50	1.66
1225	0.00	1.83	3.31	1.56
1250	0.25	2.77	4.19	1.60

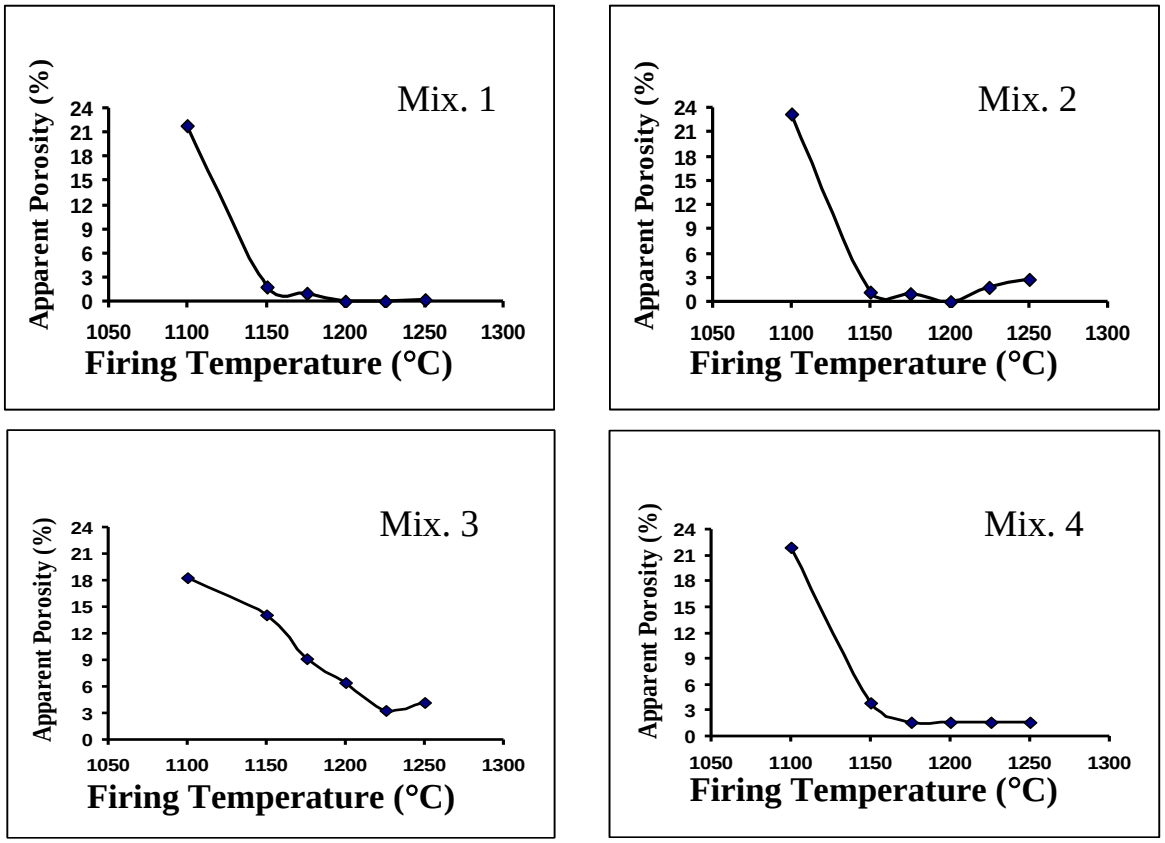

Fig. 9 Apparent porosity (%) as a function of firing temperature for the different mixes.

The observations and conclusions of these results reflect the same characteristics as those mentioned for the water absorption. The main features of the obtained results are: the minimum values of the apparent porosity were obtained at 1200 ºC (mixes 1 and 2) and at 1225 ºC (mixes 3 and 4). The use of either local albitite or Turkish albite with El-Teeh clay gave bodies free of surface pores at 1200 ºC. After maturing temperatures (1200 - 1225 ºC) the new open pores creation was enhanced, this in turn can cause the increase in the apparent porosity of the fired tile bodies.

5. 1. 4. Bulk Density

The results of bulk density of the obtained fired specimen are shown in Table 8 and illustrated in Fig.10.

Table 8 Bulk density (gm/cm^3) of the different mixes.

Temperature (ºC)	Mix. No.			
	1	2	3	4
1100	2.39	2.10	1.91	2.01
1150	2.46	2.71	2.31	2.42
1175	2.52	2.76	2.47	2.52
1200	2.72	2.95	2.50	2.53
1225	2.70	2.44	2.55	2.60
1250	2.50	2.31	2.47	2.51

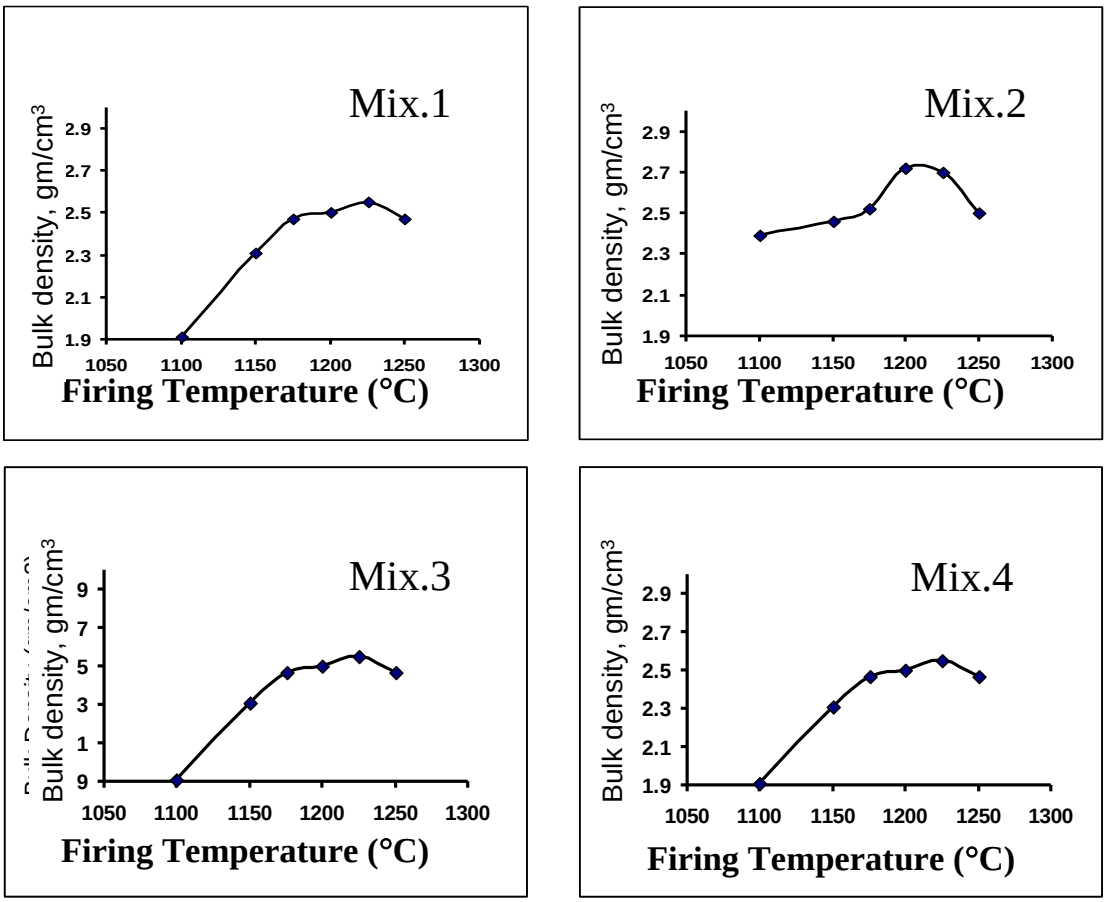

Fig. 10 Bulk density (%) as a function of firing temperature for the different mixes.

Results of bulk density showed similar behavior as displayed by firing shrinkage. In the light of the given results, the proper maturing temperature was selected. Thus, mixes 1 and 2 were matured at 1200 ºC while mixes 3 and 4 were matured at 1225 ºC. Ball clay gave bodies with slightly lower bulk densities than El-Teeh clay.

5. 1.5. X-Ray diffraction (XRD) analysis:

The microstructural changes in the specimens fired at the selected maturing temperatures were investigated by using X- ray diffraction analysis. The main crystalline phases detected were mullite, orthoclase and silica modification, namely cristobalite (Figs.11 and 12). Anorthite, is also detected in mixes 2 and 4 specimens. It has been reported that the strength would increase with increasing mullite content [27].

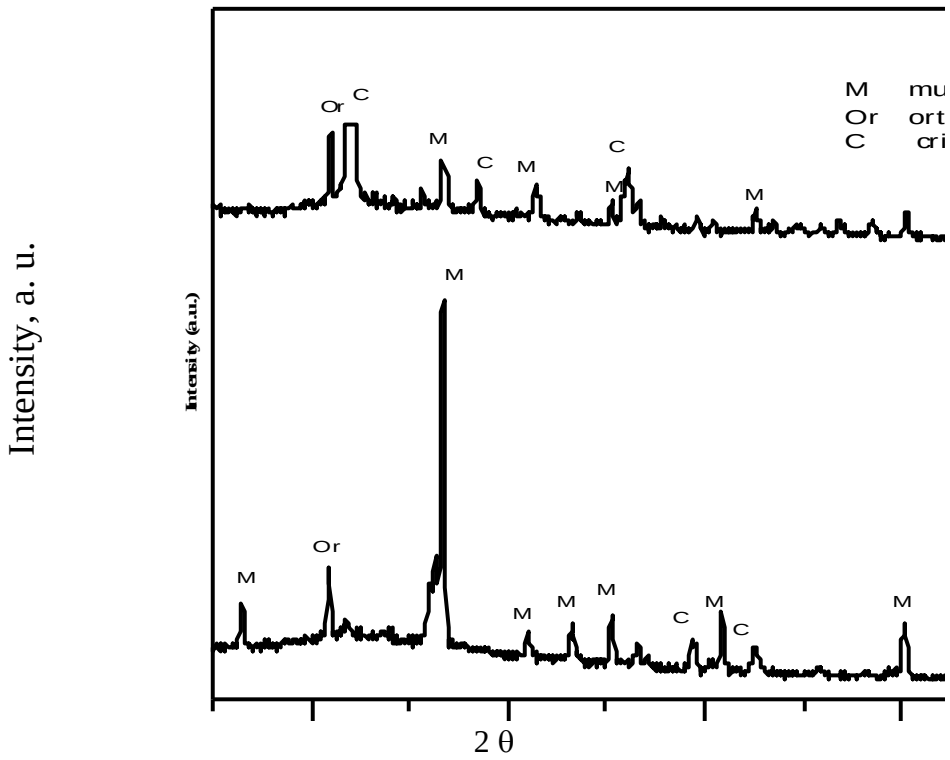

Fig.11 XRD graphically represented data for the selected specimens of mixes. 1 and 3.

Intensity, a. u.

2 θ

Fig.12 XRD graphically represented data for the selected specimens of mixes. 2 and 4.

5.1.6. Texture of Fired Bodies:

The specimens fired at the selected maturing temperatures for each mix were examined under the SEM. The shape, size and linkage trend of grains with each other played an important role in the bending strength. The irregular shaped elongated grains decrease the bending strength, in contrast, spherical grains, show relatively higher strength as shown by Isik and Zenbe [27]. The needle shaped mullite crystals are common in the SEM of mix.1 (Fig. 13a). Prismatic crystals of feldspars are clearly identified in a glassy matrix (Fig. 13b). Primary mullite patches showing better crystallinity are shown in Figs. 13c and 13d. The SEM mix.2 shows primary mullite of fine nature, the grains are not clearly identified, with scattered prismatic crystals (Fig. 14a). Networks of mullite are shown in (Fig. 14b).The growth of primary mullite grains being identified in (Figs.14c and 14d). The needle shaped mullite is the main crystalline form detected in mix.3 (Figs. 15a, 15b and 15c). Coarseness and well round shaped of mullite grains is clearly identified (Fig. 15d). Patches of fine grained primary mullite with scattered prismatic crystals are recorded in the SEM of mix. 4 (Fig.16 a).Very coarse and well rounded grains of mullite are shown in (Fig. 16 b). The presence of needle shaped mullite in a glassy matrix is also common (Figs. 16c and 16 d).

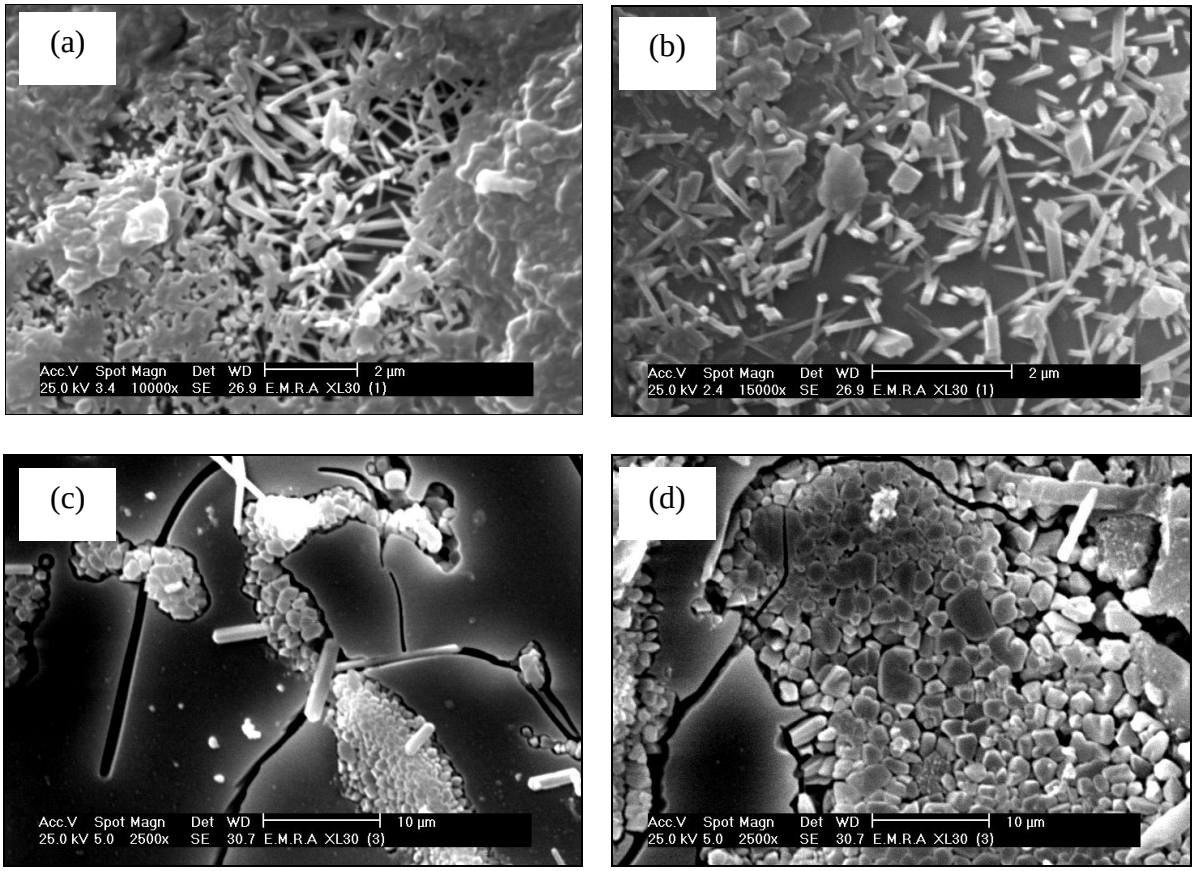

Fig. 13: SEM micrograph of the vitrified specimen from Mix 1 fired at 1200°C for 60 minutes, showing
(a) needle shaped mullite crystals,
(b) prismatic crystals of feldspar in a glassy matrix,
(c) primary mullite patches and (d) rounded mullite grains.

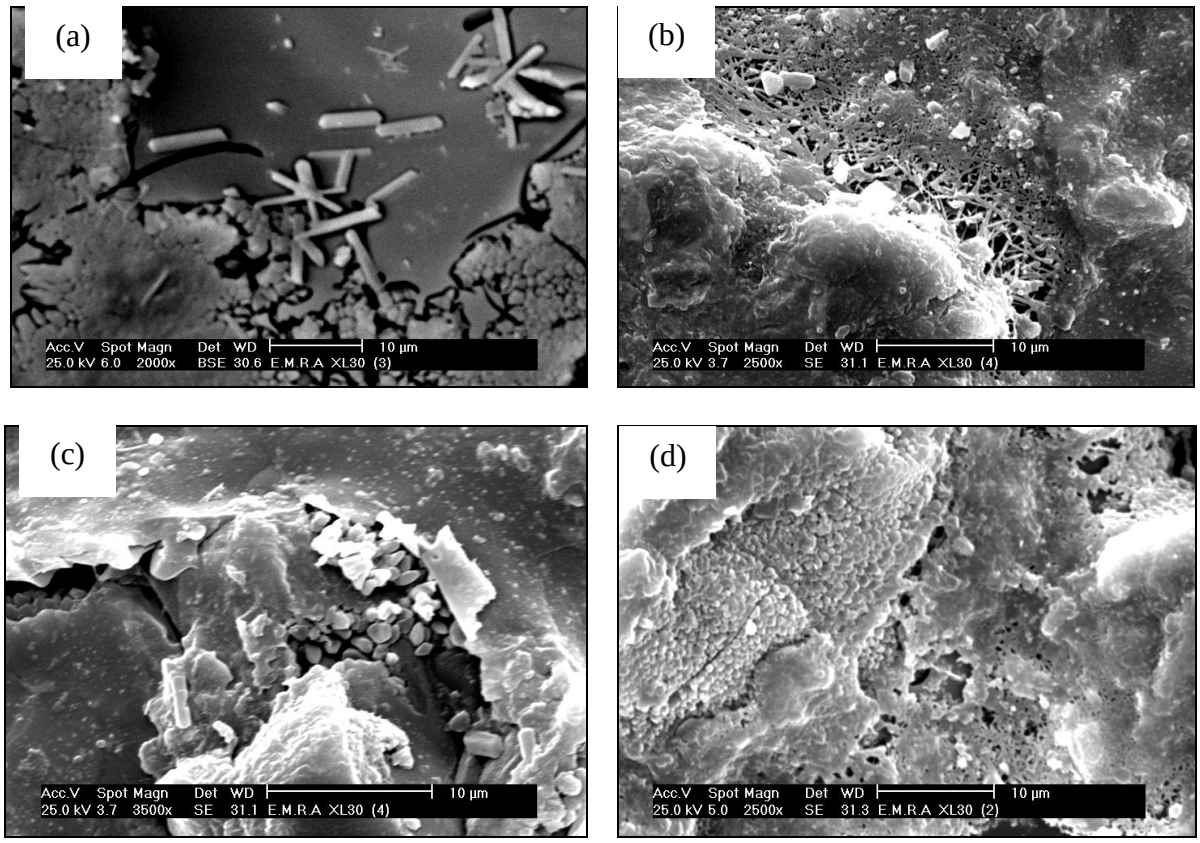

Fig. 14: SEM micrograph of the vitrified specimen from Mix 2 fired at 1200°C for 60 minutes, showing
(a) prismatic crystals of feldspar,
(b) network of mullite,
(c) primary mullite crystals and (d) growth of primary mullite.

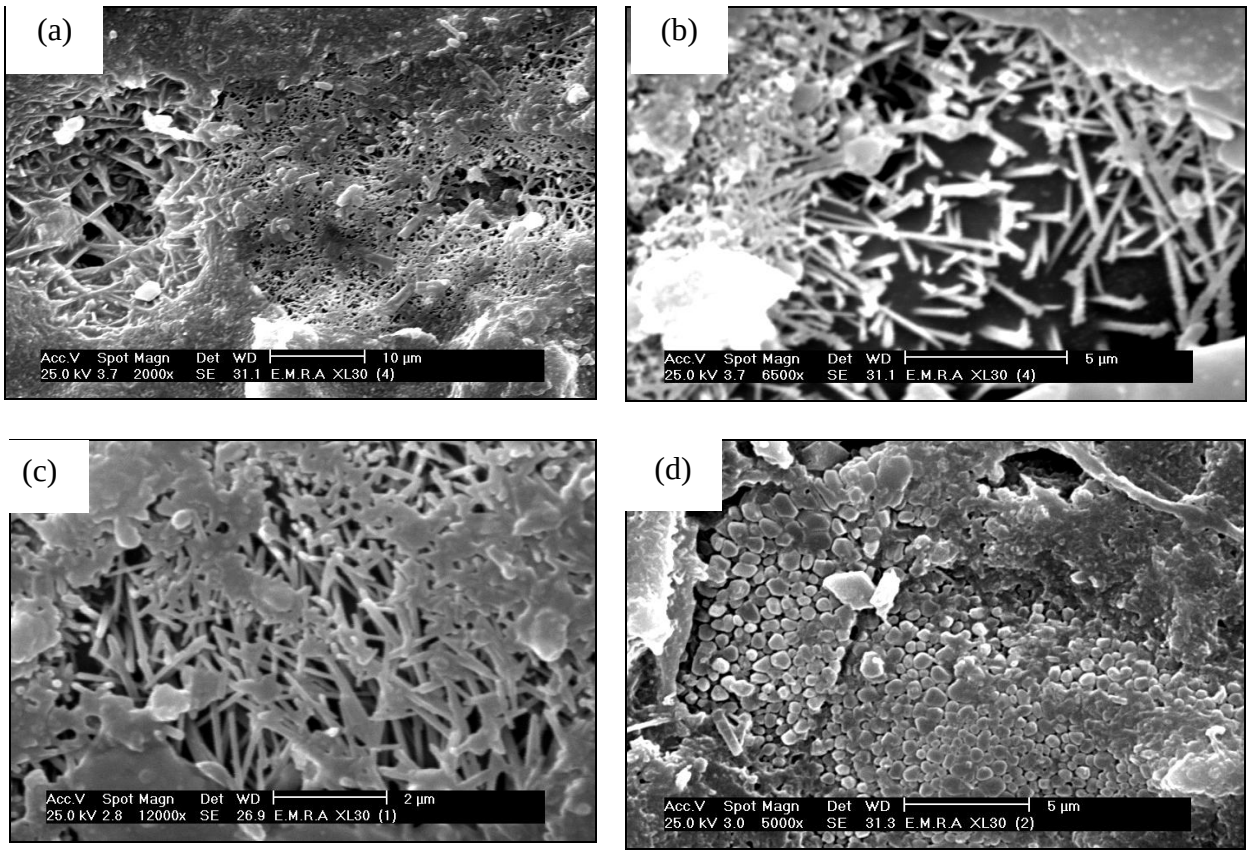

Fig. 15: SEM micrograph of the vitrified specimen from Mix 3 fired at 1225°C for 60 minutes, showing
(a) needle shaped mullite,
(b) needle shaped mullite in glassy matrix,
(c) patched of needle shaped mullite with scattered primary mullite grains
and (d) coarse and well rounded primary mullite grains.

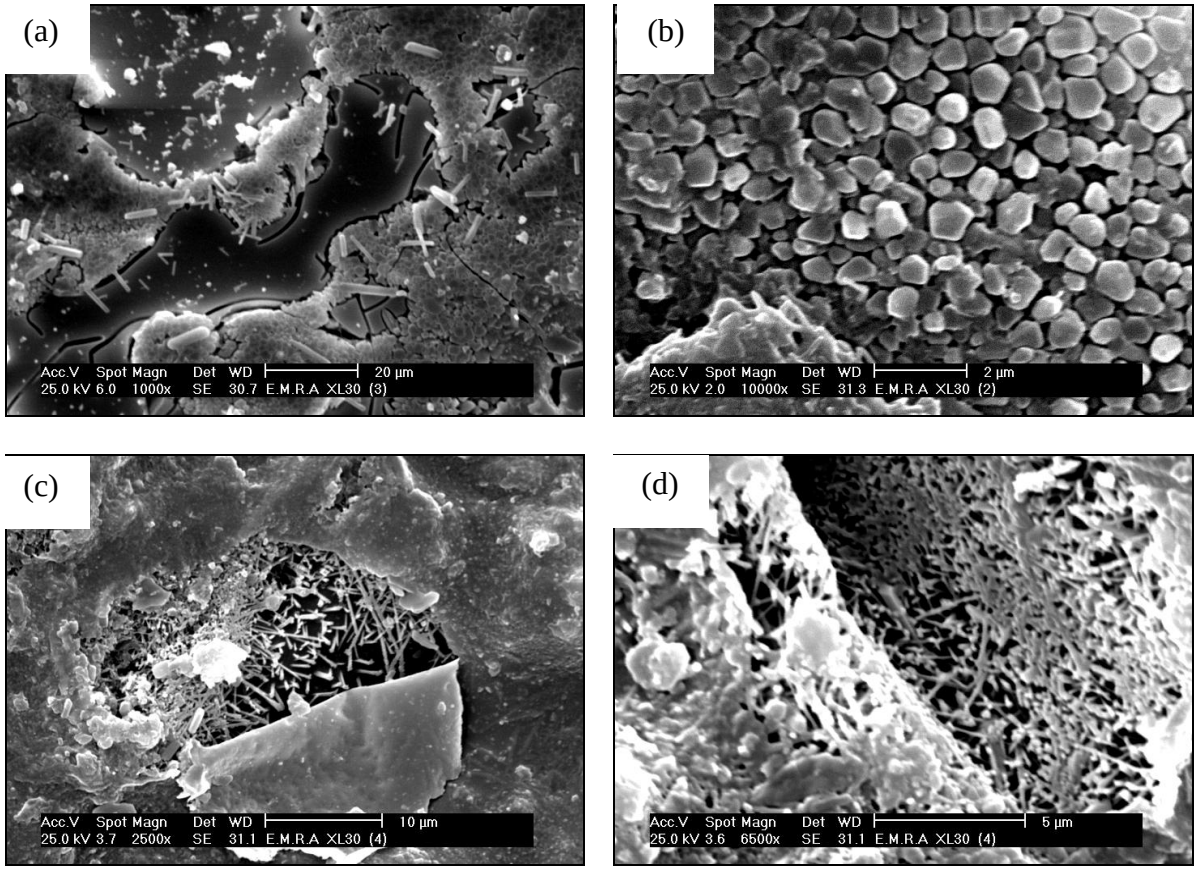

Fig. 16: SEM micrograph of the vitrified specimen from Mix 4 fired at 1225°C for 60 minutes, showing
(a) patched of primary mullite grains with scattered prismatic crystals,
(b) very coarse and well rounded primary mullite grains,
(c) patched of needle shaped mullite in a glassy matrix with scattered primary mullite grains and (d) network of mullite.

Conclusions:

The present work intends to study a new Egyptian feldspar source from Wadi Remthi southeastern Sinai, and its effect with two types of Egyptian clay (El-Teeh clay and Ball clay) on the production of ceramic tiles. Egyptian clays from El-Teeh, Sinai Peninsula and Abu Sbeira gully, North Aswan were chosen. El-Teeh and Abu Sbeira, represent kaolin and ball clay sources respectively required for tile recipes. Remthi albitite (the new feldspar source) and Turkish albite are used in this study. White sand collected from Zafarana is used in all mixes. The results presented and discussed in this work enable to draw the following conclusions:

1. The XRD of the studied samples shows that, Remthi albitite is mainly represented by albite-anorthite solid solution, quartz and slight amount of orthoclase.
2. Remthi albitite has good grindability, since producing ultrafine size (2-3 µm) of powders that would enhance the physical and mechanical properties of the products.

3. Remthi albitite (the new feldspar source) can be used in Egyptian ceramic industries producing specimens having more dense, and lower water absorption compared with that produced by Turkish albite.
4. From the ceramic characteristic parameters, it is obvious that, the using of El-Teeh clay with either local albitite or Turkish albite lowers the maturing temperature of the produced bodies from 1225 t0 1200 ºC and improves bulk density compared with Ball clay.
5. The different crystalline phases developed by firing were mullite, orthoclase and silica modification namely cristobalite, anorthite were detected in mixes 2 and 4.

REFERENCES:

[1] ***R. Askeland,*** The Science and Engineering of Materials, third edition, PWS Publishing Company, 20 Park Plaza, Boston, (1994) pp. 417-464.

[2] ***W. D. Kingery,*** Introduction to Ceramics, John Wiley and Sons, Inc., New York, (1960).

[3] ***Y. Kobayashi, O. Ohira, H. Isoyama,*** Effect of particle size of raw materials on densification and bending strength of porcelain, Journal of the Ceramic Society of Japan, 108 (1262) (2000) pp. 921-925.

[4] ***I. Teoreanu, R. Dumitrache,*** Study concerning the grinding of the glazes for porcelain obtained by fast firing, Key-Engineering-Materials, 206-213 (III) (2001) pp. 1779-1782.

[5] ***K. Swapan, D. Kausik,*** Differences in densification behavior of K- and Na-feldspar containing porcelain bodies, Thermochimica Acta, 406 (1-2), (2003) pp. 199- 206.

[6] ***N. F. Youssef. M.O. Shater. M.F. Abadir, O. A. Ibrahim,*** Utilization of red mud in the manufacture of ceramic tiles, Key Engineering Materials, 206-213 (2002) pp. 1775-1778.

[7] ***M. F. Abadir, E. H. Sallam, I. M. Bakr,*** Preparation of porcelain tiles from Egyptian raw materials, Ceramics International 28 (2002) pp. 303-310.

[8] ***N. Ediz , A. Yurdakul,*** Characterization of porcelain tile bodies with colemanite waste added as a new sintering agent, Journal of Ceramic Processing Research, 10 (4) (2009) pp. 414-422.

[9] ***P. Torres, H. R. Fernandes, S. Agathopoulos, D.U. Tulyaganov, J.M. Ferreira,*** Incorporation of granite cutting sludge in industrial porcelain tile formulations, Journal of the European Ceramic Society, 24 (2004) pp. 3177-3185.

[10] ***S. Ferrai, A. F Gualtieri,*** The use of illitic clays in the production of stoneware tile ceramics, Applied Clay Science, 21 (1-2) (2005) pp. 147-156.

[11] ***S. Naga,*** Effect of compositions and firing conditions of some building materials, Ph.D thesis, Faculty of Science, Cairo university (1983).

[12] ***D. Ibrahim, A. Mostafa,*** Two-steps firing of phosphate-modified ceramic compositions, Interceram International Ceramic Review, 5 (2002) pp. 6-12.

[13] ***E. El-Fadaly, I. M. Bakr, M. R. Abo Breka,*** Recycling of ceramic industry wastes in floor tiles recipes, Journal of American Science, 6 (10) (2010) pp. 241- 247.

[14] ***Y. Hirata, A. Yoshitomi, S. Sameshima, Reaction,*** microstructures and mechanical properties of model ceramic ware in K_2O-Al_2O-SiO_2 system, Journal of the Ceramic

Society of Japan, 1296 (III) (2003) pp. 560-566.

[15] ***K. Dana, S.K. Das,*** Effect of Na-feldspar and K-feldspar on the whiteness and other properties of porcelain bodies, Industrial-Ceramics, 24 (2) (2004) pp 91-95.

[16] ***M. Dondi, G. Guarini, I. Venturi,*** Assessing the feasibility of feldspathic fluxes for ceramic tiles by hot stage microscope, Industrial-Ceramics, 21 (2) (2001) pp. 67-73.

[17] ***K. Gamlem, S. Lyng,*** Anorthosite as a Ceramic Raw Material, II. Anorthosite for tile manufacture, Transactions British Ceramics. Society, 73 (5) (1974) pp 139-142

[18] ***C. Fiori, B. Fabbri,*** Granite containing bodies for the production of stoneware tiles, Interceram, 32 (1) (1983) pp. 21-22.

[19] ***F. Cravero, I. Gonzalez, E. Galan,*** E. Dominguez, Geology, mineralogy, origin and possible applications of some Argentinian kaolins in the Neuquen basin, Applied Clay Science, 12 Issues1-2, (1997) pp. 27-42.

[20] ***Klein, Ersen,*** A comparative view of the application of feldspar and nepheline syenite raw materials used as fluxing agent in silicate ceramics materials, part II. Keramische Zeitschrift, 53(12) (2001) pp 1096-1101.

[21] ***K. Swapan, D. Kausik,*** Differences in densification behavior of K- and Na-feldspar containing porcelain bodies, Thermochimica Acta, 406 (2003) pp. 199- 206.

[22] ***G. Carani, P. Generali,*** Glazed and unglazed porcelain stoneware tiles, Ceramica Acta, 4-5 (1998) pp. 46-47.

[23] ***J. Mcllvian, Ceramic tile,*** The Construction Specifier, 47 (5) (1994) pp.126-136.

[24] ***M. AW. Gaber,*** Evaluation of some natural ores from Egyptian eastern desert to be utilized in producing of paint materials, Journal of Petroleum and Gas Exploration Research, 2 (1) (2012) pp.17-26.

[25] ***S. Chandrasekhar,*** P. N. Pramada, Sintering behavior of calcium exchanged low silica zeolites synthesized from kaolin, Ceramics International, 27 (1) (2001) pp. 105-114.

[26] ***A. Mostafa,*** Ceramic floor tiles from Egyptian raw materials, M.Sc. Thesis, faculty of science, Zagazig University (1989).

[27] ***O. Isik, E. Zenbe,*** Bending strength of porcelains, Journal of the Ceramic Society of Japan, 118 (1542) (2002) pp.827-838.