

# Diatomic heat insulating material combined by ceramic bond

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## ABSTRACT

Based on the existing demands of some types of heat insulating materials in Egyptian industries, this work is directed to employ the Egyptian diatomite in their preparation. Therefore, five diatomite samples were employed for this purpose cooked rice hulls and saw-dust were added to each sample as pore former agent in amount of 5 to 20 mass % and 2.5 to 15 mass % respectively. After mixing with water and shaping, the dried specimens are fired at temperature up to 1100°C. The changes in their physical properties, microstructure and mineral composition under different preparation conditions are studied. When both pore former agents are added to the specimens, their bulk density was reduced. The strong effect appears on the bulk density of saw-dust containing specimens. Diatomite specimens of 0.68 to 0.83 g.cm<sup>-3</sup> bulk density, 69 to 74 open porosity, 0.5 to 1.4 MPa compressive strength and 1100°C application temperature are obtained. Their chemical composition affected their thermal stability. When the value of Al/ (Al + Si) is low compared with the values of Ca/Si and Ca/ (Al + Si) atom ratio, low amount of glassy phase was formed in the specimens fired at 1100°C, and hence they are thermally stable at this temperature. Their pores are divided into minute and macro pores. The minute pores, in the specimens fired at 1100°C, are preserved with decreasing impurities content. The shape and size of macro pores (<50 μm) are effected with type and amount of pore former agent.

**Keywords:** Diatomite, cooked rice hulls, saw-dust, porous materials.

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## INTRODUCTION

As known, diatomite is a naturally occurring material from geological deposits composed predominantly of fossilized skeletons of unicellular plants. These plants are extremely abundant and inexpensive source of silica. It can be found at higher purity or may contain impurities such as sand, clay, calcite, marl and tuff (Yilmaz and Ediz, 2008; Yang et al., 2003). Due to its porous and permeable structure, its resistance to chemicals and its large surface area, diatomite can be used as filter aid, absorbent, thermal insulator, mild abrasive, filler and insecticide (Yang et al., 2003; Ibrahim and Selim, 2012).

Heat insulating diatomite bricks are often moulded by one of the three methods; semi-dry, plastic and foam slip. Saw-dust or coke is often used as pore former agent (Kashcheev et al., 2009). After moulding into bricks and drying the bricks were fired to temperature of 1000°C.

Objects made of diatomite occupy a leading position for use as heat insulation in different production fields (Belyakov and Ivanov, 2008). Diatomite bricks are employed in design of thermal insulation for furnaces. This is due to their low thermal conductivity, high strength and chemical resistance. Therefore, diatomite bricks are employed as heat insulating material in electrolyzers for melting primary aluminium (Kashcheev et al., 2009). It was proposed to build roofs, walls and kiln cars in stead of insulating fireclay brick in tunnel kiln with diatomite bricks (Kashcheev et al., 2009; Tsibin, 1966). However, a relative disadvantage of diatomite is the comparatively low application temperature, 900 to 950°C. This is due to the formation of a liquid phase in diatomite objects as a result of reaction of amorphous silica with impurities (Belyakov and Ivanov, 2008). A search work was carried

**Table 1.** Chemical composition of fired specimens.

%	Masakheet	Demia yellow	Kasr El Sagha	Demia grey	Kom Osheem
SiO <sub>2</sub>	69.00	62.52	37.76	57.90	59.88
Al <sub>2</sub> O <sub>3</sub>	2.34	5.11	5.26	10.58	11.46
CaO	21.23	21.51	45.28	20.17	14.64
Fe <sub>2</sub> O <sub>3</sub>	1.12	2.88	3.49	5.51	7.66
MgO	1.91	1.57	1.94	2.38	2.79
Na <sub>2</sub> O	1.20	1.25	0.60	0.42	0.36
K <sub>2</sub> O	0.56	0.74	0.87	1.06	1.20
Ca/Si	0.33	0.37	1.28	0.37	0.26
Ca/(Al+Si)	0.32	0.33	1.10	0.31	0.21
Al/(Al+Si)	0.04	0.09	0.14	0.18	0.18

out for increasing the application temperature of diatomite objects up to 1100°C (Kashcheev et al., 2009). This work is based on addition of chalk (CaCO<sub>3</sub>) to diatomite. This addition increases the temperature at which liquid phase is formed and hence the operating temperature increases up to 1100°C.

In Egypt, most of diatomite deposits are located north of Fayoum depression. These deposits were formed in a fresh water lake that covered most of Fayoum depression in Holocene (lakes Moeris) (Hassan et al., 1999; Zalat, 2002). These diatomaceous earth deposits consist of three main constituents the carbonates, the diatomite and quartz and clay minerals (Loukina et al., 1994). The lake received drainage from the surrounding formations and that drainage was responsible for the existence of high content of fine-grained calcium carbonate in these deposits (Basta et al., 1972).

On the other hand, the Egyptian industry is in a real need to some types of heat insulating materials which could be applied at temperatures up to 1000°C. The diatomite ore deposits of Fayoum depression with its unique physical and chemical features are not exploited at all. Therefore, the present paper aims to employ the diatomite deposits of Fayoum region with CaO content varied between ~15 and 45% in preparation of heat insulating diatomite material. Through this work, the effects of composition of employed diatomite samples, type and amount of used pore former agent and firing temperature on properties, mineral composition and microstructure of obtained diatomite products were studied.

## MATERIALS AND METHODS

### Materials

The employed materials are five diatomite samples representing five localities, Masakheet, Demia yellow, Kasr El Sagha, Demia grey and Kom Osheem in Fayoum region. The chemical composition of these samples are

shown in Table 1. Their BET surface area are 190, 178, 119, 86 and 75 m<sup>3</sup>/g, respectively. Cooked rice hulls and saw-dust samples were used as pore forming agents. Cooked rice hulls were prepared by coking rice hulls at temperature of 600°C. The obtained hulls contain ~ 55 mass % carbon, ~ 42 mass % silica and some impurities. Their grain size is less than 76 µm. On the other side, 96 mass % of saw-dust is carbon and volatile matter and it has coarser particle size.

### Test – specimens' preparation

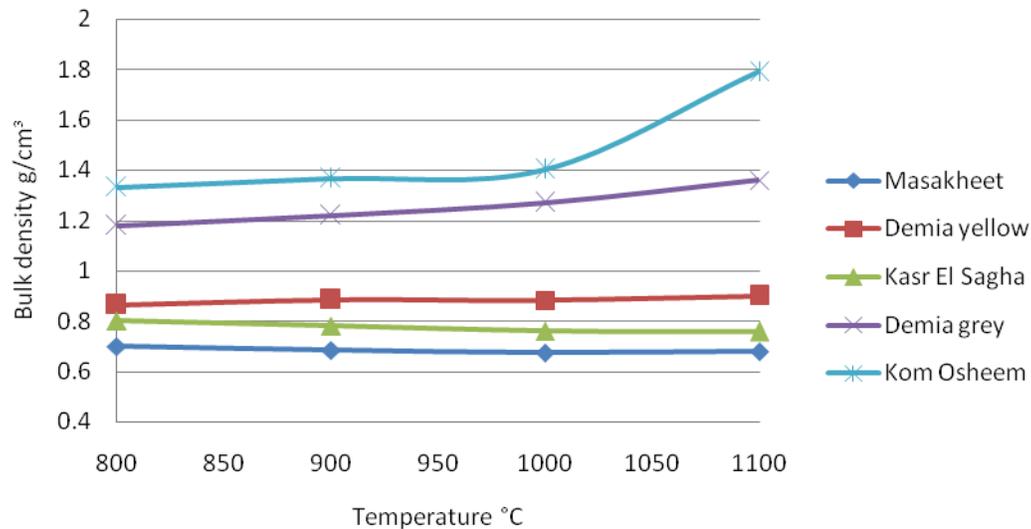
Cooked rice hulls and saw-dust were added separately to each diatomite sample in amounts of 5 to 20 mass % and 2.5 to 15 mass %, respectively. During mixing the constituents, appropriate amount of water (~ 25 mass %) is added in parts. The resulted mass was moulded and tamped under a light pressure into small cubic specimens of two inches length. The specimens were left to dry at ambient temperature for 48 h and then at 110°C for 24 h. Then dried specimens were first fired at 600°C to burn out the additives and second at temperature of 1100°C for 2 h.

### Testing methods

Specific surface area and chemical composition of the five diatomite samples were determined using Brunauer-Emmett-Teller and X-ray fluorescence (XRF).

The physical properties of fired specimens such as bulk density and open porosity are determined by water displacement method after boiling for 2 h to eliminate residual air bubbles. A vernier caliber with a precision of 0.005 cm was employed to measure the change in dimensions of specimens. The measurement of compressive strength of specimens is carried out in a universal testing machine of Seidner, Riedlinger type, Germany at a crosshead speed of 1 mm.min<sup>-1</sup>.

After the strength test, the samples were used for the



**Figure 1.** Effect of firing temperature on bulk density of five diatomite specimens.

studies of mineralogical and morphological compositions using X-ray diffraction analysis (XRD) and scanning electron microscopy. X-ray diffraction patterns were obtained using a Philips X-ray diffractometer Model PW / 1710 Cu  $k\alpha$  radiation with Ni filter. Care was taken to keep the X-ray unit constant at 40 kV and 30 mA. The scanning speed was chosen to be  $2^\circ / \text{min}$ . The obtained X-ray patterns were correlated and compared with the ASTM cards for the expected phases. On the other side, the fracture surface of some fired specimens were cleaned and then coated with thin layer of gold under vacuum. The scanning electron microscope photographs were carried out using SEM Model Philips XL30 with accelerating voltage 30 kV.

To determine the permanent change in dimension of fired specimens at temperature of  $1100^\circ\text{C}$ , they are heated for 2 h at this temperature. After cooling, their dimension is measured and the change in dimension is calculated.

To assess the corrosion resistivity of some prepared specimens to molten aluminium. A piece of pure aluminium metal is placed on the surface of specimen and fired together for 2 h at  $800^\circ\text{C}$ . The degree of attack and penetration of aluminium is noted.

## RESULTS AND DISCUSSIONS

### Physical properties of fired specimens

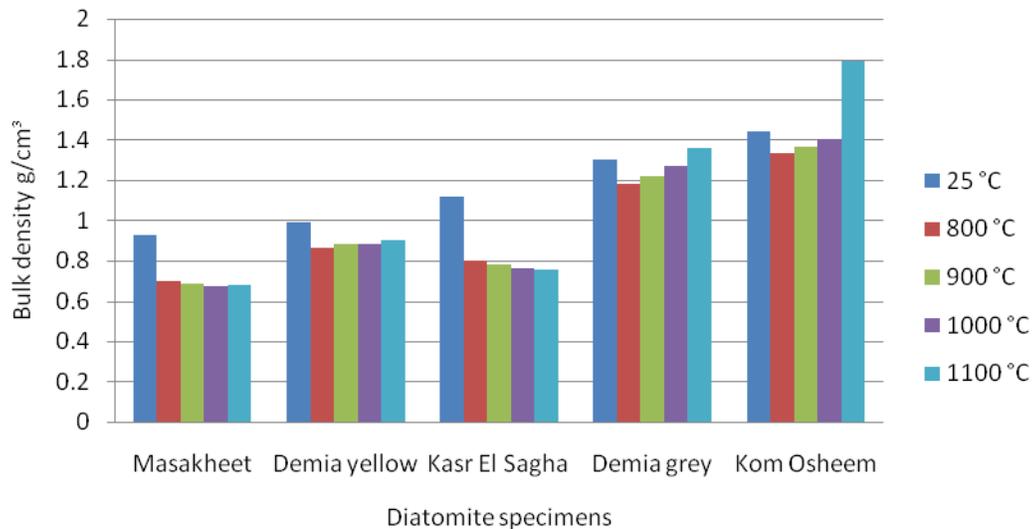
Figures 1 and 2 show the effect of firing temperature on the bulk density of five diatomite specimens. As shown, the relationship between bulk density of fired specimens and firing temperature can be divided into two parts. When the firing temperature increases from ambient temperature to temperature of  $800^\circ\text{C}$  the bulk density of

specimens decreases. Some changes in their chemical composition occur in this temperature range such as evolution of adsorbed and mixing water, dehydroxylation of clay minerals, oxidation of organic matter and decomposition of calcite ( $\text{CaCO}_3$ ). These leads to loss in the mass of specimens and hence their bulk density was reduced. This appears more clearly in Kasr El Sagha specimens where this diatomite sample contains relatively large amount of calcite (Table 1).

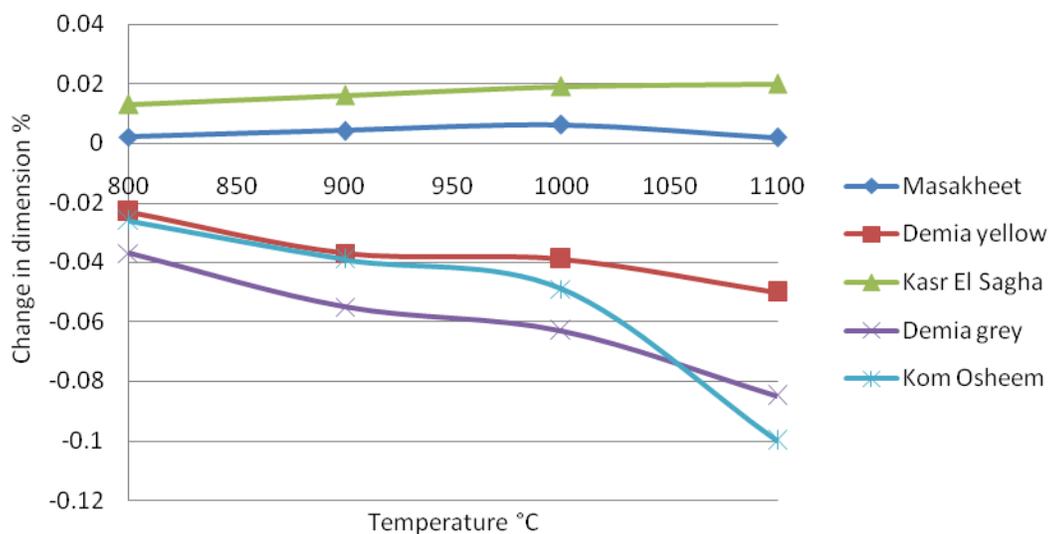
When the firing temperature increases from  $800$  to  $1100^\circ\text{C}$ , the fired specimens are divided owing to the change in their bulk density into two groups. Demia grey and Kom Osheem specimens have the higher values of bulk density,  $1.3$  and  $1.44 \text{ g}\cdot\text{cm}^{-3}$ , respectively. Their bulk density increases with increasing firing temperature. The strong effect appears in Kom Osheem specimens fired at temperature of  $1100^\circ\text{C}$ . On the other hand, Masakheet, Kasr El Sagha and Demia yellow specimens show bulk density values of  $0.68$ ,  $0.76$  and  $0.9 \text{ g}\cdot\text{cm}^{-3}$ , respectively. The relationship between firing temperature and bulk density of specimens could be represented by a straight line with nearly no change in the values of bulk density of specimens.

Figure 3 shows the effect of firing temperature on the change in dimension of five diatomite specimens. As shown, Masakheet and Kasr El Sagha diatomite specimens show a slight expansion in their dimension on firing them in the temperature range of  $800$  to  $1100^\circ\text{C}$ . Nearly no change in the values of expansion is noted. On the other hand, the fired specimens of the other three diatomite samples suffer shrinkage in their dimension. This appears more clearly with relatively large change in its values in the fired specimens prepared from Demia grey and Kom Osheem diatomite specimens, but the values do not exceed  $-0.1\%$ .

Figure 4 shows open porosity of the five diatomite



**Figure 2.** Bulk density of five diatomite specimens fired from room temperature up to 1100°C.



**Figure 3.** Effect of firing temperature on change in dimension of five diatomite specimens.

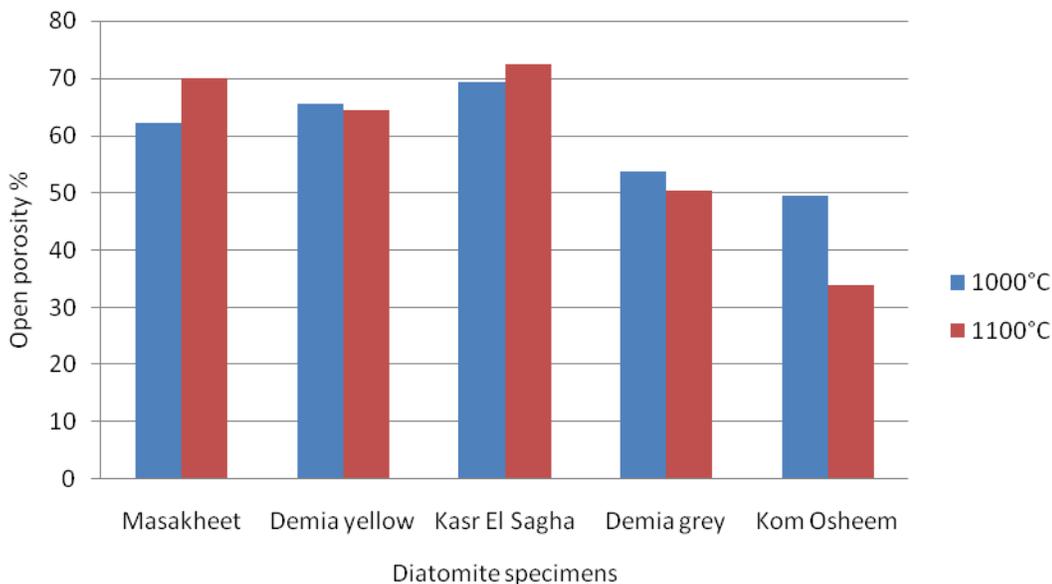
specimens fired at temperature of 1000 and 1100°C. The results of open porosity of specimens confirm those of bulk density and change in dimension of specimens where open porosity of Masakheet and Kasr El Sagha specimens increases when they are fired at temperature of 1100°C. On the other hand, there is a decrease in the open porosity of the other three diatomite specimens. The strong effect appears in the open porosity of Kom Osheem diatomite specimens, 49.48 and 33.79%, respectively.

Figure 5 shows the effect of firing temperature on the bulk density of both additives containing Masakheet, Demia yellow and Kasr El Sagha diatomite specimens.

When both cooked rice hulls and saw-dust were

introduced in these specimens, the bulk density of fired specimens was reduced. The strong effect appears on bulk density of saw-dust containing specimens. This is due to its relatively coarse particle size and large volatile matter evolving during its burning out (96%). However, using cooked rice hulls as a pore former agent increases the active silica content of specimens, where the used cooked rice hulls contain 42.44 mass % silica. Furthermore, finer pores are created after their burning out in diatomite specimens.

As shown in Figure 5, there is a slight decrease in the bulk density of both Masakheet and Kasr El Sagha diatomite specimens when firing temperature was raised from 800 to 1100°C. This appears clearly in Kasr El



**Figure 4.** Open porosity % of five diatomite specimens fired at 1000 and 1100°C.

Sagha specimens. On the other hand, a slight increase in the bulk density of Demia yellow specimens took place with increasing firing temperature up to 1100°C. This appears clearly incooked rice hulls specimens and diminishes in saw-dust containing counterparts. This difference in behaviour is due to their variation in mineral composition as mentioned later.

Figure 6 shows the effect of firing temperature on the bulk density of both additives containing Demia grey and Kom Osheem diatomite specimens.

As shown, the change in bulk density of Demia grey and Kom Osheem diatomite specimens under effect of increasing firing temperature or additive content is nearly resembled. An increase in the bulk density of the two specimens with increasing firing temperature occurs while the effect of additive content on reducing their bulk density decreases. The bulk density of specimens fired at 1000 and 1100°C is higher than those of unfired specimens. Specimens of  $< 1 \text{ g.cm}^{-3}$  bulk density could not be obtained under these preparation conditions from the two diatomite samples.

Figure 7 shows the effect of firing temperature on the change in dimension of both additives containing Masakheet, Demia yellow and Kasr El Sagha diatomite specimens. As shown, Masakheet and Kasr El Sagha diatomite specimens show a slight expansion in their dimension in temperature range of 800 to 1100°C, while Demia-yellow diatomite specimens suffer a shrinkage in their dimension.

Figure 8 shows the effect of firing temperature on the change in dimension of both additives containing Demia grey and Kom Osheem diatomite specimens. As shown, all the specimens prepared from the two diatomite samples suffer shrinkage in their dimension. This

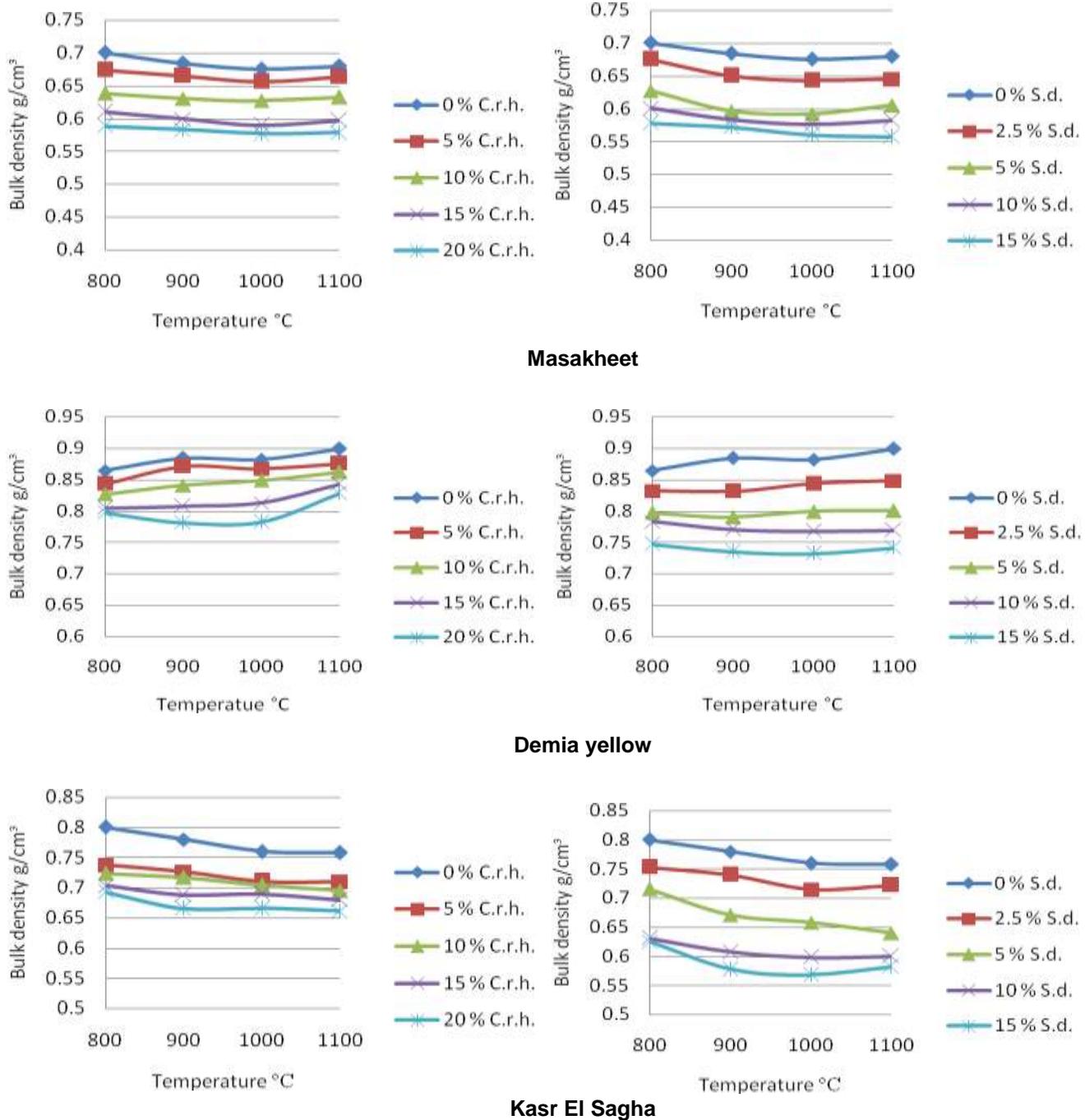
appears more clearly in the specimens fired in the temperature range of 1000 to 1100°C.

### Mineral composition

Figure 9 shows the X-ray diffraction patterns of diatomite specimens fired for 1h at temperature of 1100°C. As shown from this Figure 8 and Table 1, the mineral composition of fired diatomite specimens is effected by their chemical composition as follows:

a) The X-ray diffraction pattern of fired Masakheet diatomite specimen reveals three main phases: wollastonite ( $\text{CaO} \cdot \text{SiO}_2$ ), diacalcium silicate ( $2\text{CaO} \cdot \text{SiO}_2$ ) and gehlenite ( $2\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{SiO}_2$ ) beside unreacted quartz. Weak X-ray diffraction pattern of anorthic albite ( $\text{NaCa} \text{ Al} (\text{Si} \cdot \text{Al})_3\text{O}_8$ ) was detected in this specimen. This may be due to the relatively low value of  $\text{Al} / (\text{Al} + \text{Si})$  atom ratio compared with the other two values of  $\text{Ca}/\text{Si}$  and  $\text{Ca} / (\text{Al} + \text{Si})$  atom ratios in this specimen.

b) On increasing the value of  $\text{Al} / (\text{Al} + \text{Si})$  atom ratio from 0.04 in Masakheet to 0.09 in Demia yellow diatomite specimens, albite was formed beside gehlenite and wollastonite. The formation of albite decreases the amount of formed gehlenite, where the increase in the value of  $\text{Ca} / (\text{Al} + \text{Si})$  atom ratio from Masakheet to Demia yellow diatomite specimens is not high enough to form relatively large amount of gehlenite, 0.32 and 0.33, respectively. Relatively small amount of diacalcium silicate was also formed in Demia yellow diatomite specimen because the increase in the value of  $\text{Ca}/\text{Si}$  atom ratio is not high enough to form diacalcium silicate beside wollastonite, 0.33 and 0.37, respectively.

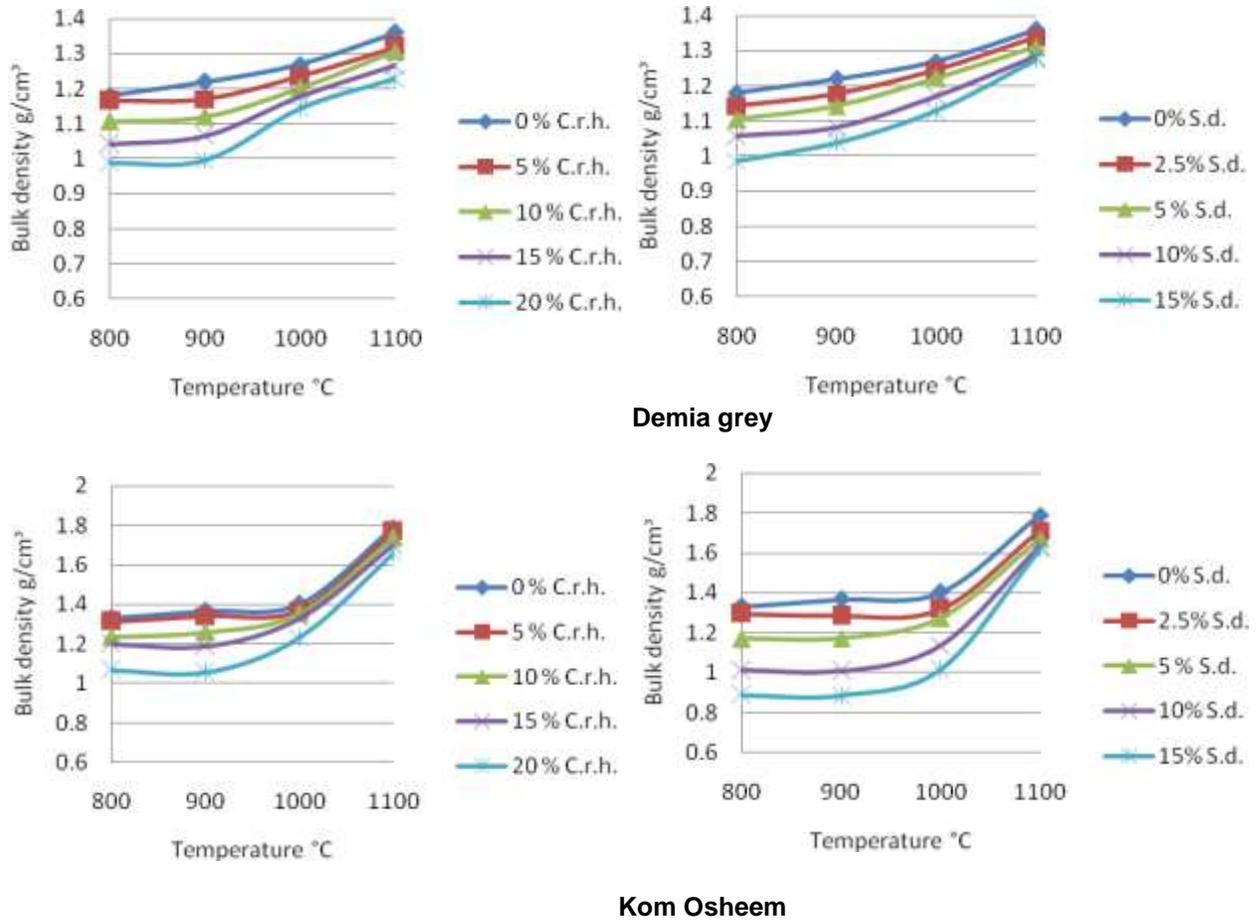


**Figure 5.** Effect of firing temperature on bulk density of both additives containing Masakheet, Demia yellow and Kasr El Sagha diatomite specimens.

c) Relatively high values of Ca/Si, Ca/ (Al + Si) and Al/ (Al + Si) atom ratios were found in Kasr El Sagha specimen compared with Demia yellow one. However, the increase in the values of Ca/Si and Ca / (Al + Si) atom ratios is relatively high. This leads to the formation of gehlenite as a main phase, wollastonite and dicalcium silicate as second ones and nearly disappearance of anorthic albite

in X-ray diffraction pattern of this specimen. As a result of formation of these phases, relatively small amount of unreacted quartz was detected because this sample has the lowest silica content among the investigated diatomite samples (37.76 mass %).

d) Comparing the chemical composition of Demia grey with Demia yellow diatomite specimens, there is relatively



**Figure 6.** Effect of firing temperature on bulk density of both additives containing Demia grey and Kom Osheem diatomite specimens.

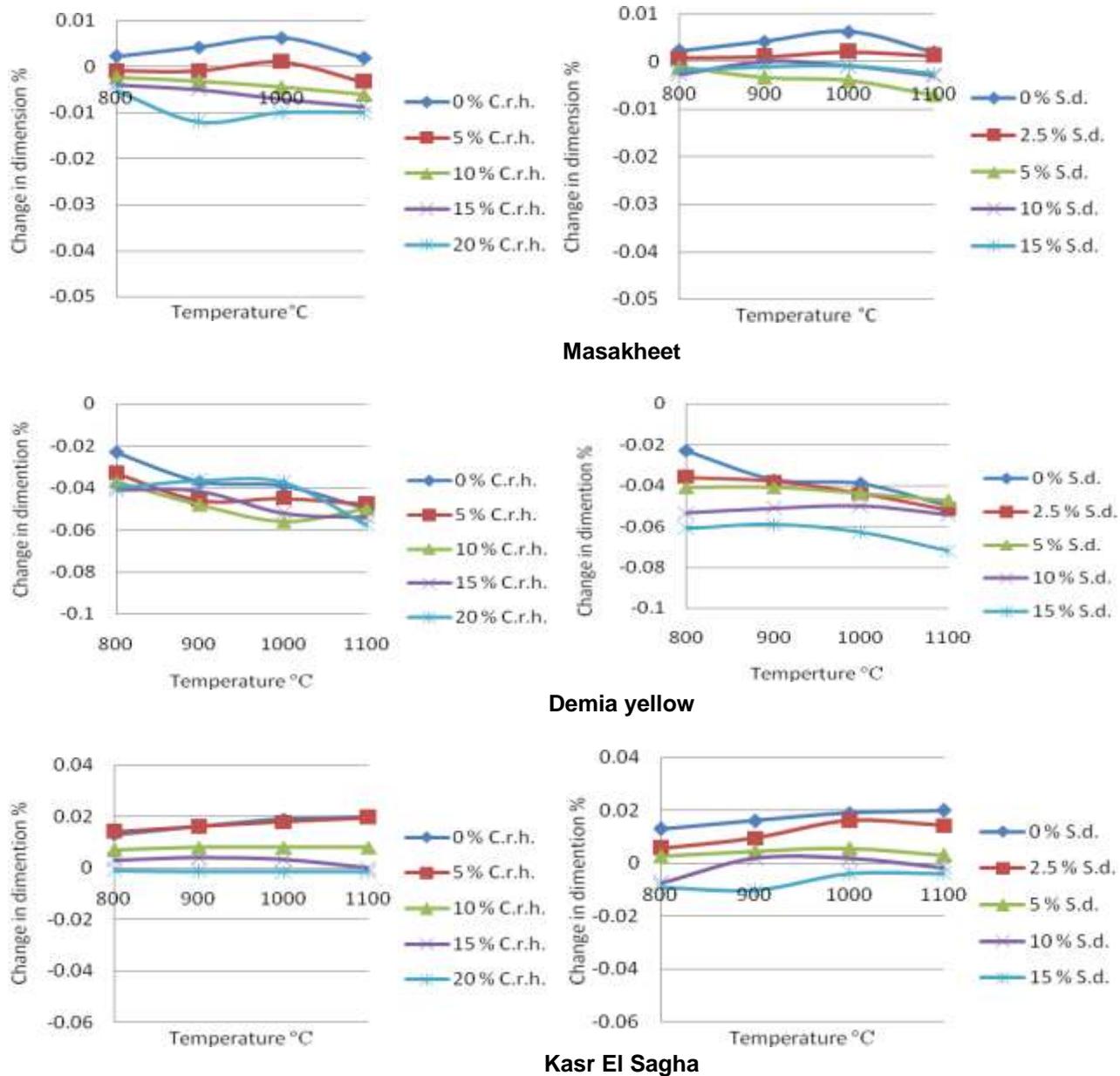
high increase in the value of Al/ (Al + Si) and a decrease in the value of Ca/ (Al +Si) atom ratio in Demia grey diatomite specimen. There is also no change in the value of Ca/Si atom ratio between the two specimens. As a result of this, albite was formed as a second phase after wollastonite and the amount of formed gehlinit decreased in Demia grey diatomite specimen.

e) There is no change in the value of Al/ (Al + Si) atom ratio between Kom Osheem and Demia grey diatomite specimens. However, relatively low values of Ca/Si and Ca/ (Al + Si) atom ratios are found in Kom Osheem specimens. This leads to an increase in the formation of anorthic albite at the expense of gehlinit and wollastonite. Another remark is that relatively high background of X-ray diffraction patterns of both specimens is detected. This denotes that a considerable amount of glassy phase was formed during firing the two specimens.

**General consideration**

The calcium oxide content of the five investigated

samples reacted with cristobalite on firing to form wollastonite (CaO.SiO<sub>2</sub>) and small amount of dicalcium silicate (2CaO.SiO<sub>2</sub>). Wollastonite exhibits high melting point 1544°C and has a favoue thermal shock resistance of diatomite particles due to its low thermal coefficient. However, the five investigated diatomite specimens contain aluminium oxide beside calcium oxide and silicon dioxide. Its content in fired specimens ranges from 2.34 mass % in Masakheet specimen to 11.46 mass % in Kom Osheem specimens. Consequently, the mineral composition of fired specimens depends as shown on the values of Ca/Si, Ca/ (Al + Si) and Al/ (Al + Si) atom ratios in their chemical composition. In Demia grey and Kom Osheem diatomite specimens the value of Al/ (Al + Si) atom ratio is high compared with the values of Ca/Si and Ca/ (Al + Si) atom ratios. Therefore, albite anorthic beside wollastonite and unreacted quartz were formed. Their phase composition lies in the triangle CaO.SiO<sub>2</sub> - CaO.AlO<sub>3</sub>.2SiO<sub>2</sub> - SiO<sub>2</sub> of phase diagram for CaO - Al<sub>2</sub>O<sub>3</sub> - SiO<sub>2</sub> system (Figure 10). The firing temperature is close to the eutectic point at 1170°C. Therefore, a considerable amount of glassy phase was formed in the two specimens. It was detected from the notable height of the



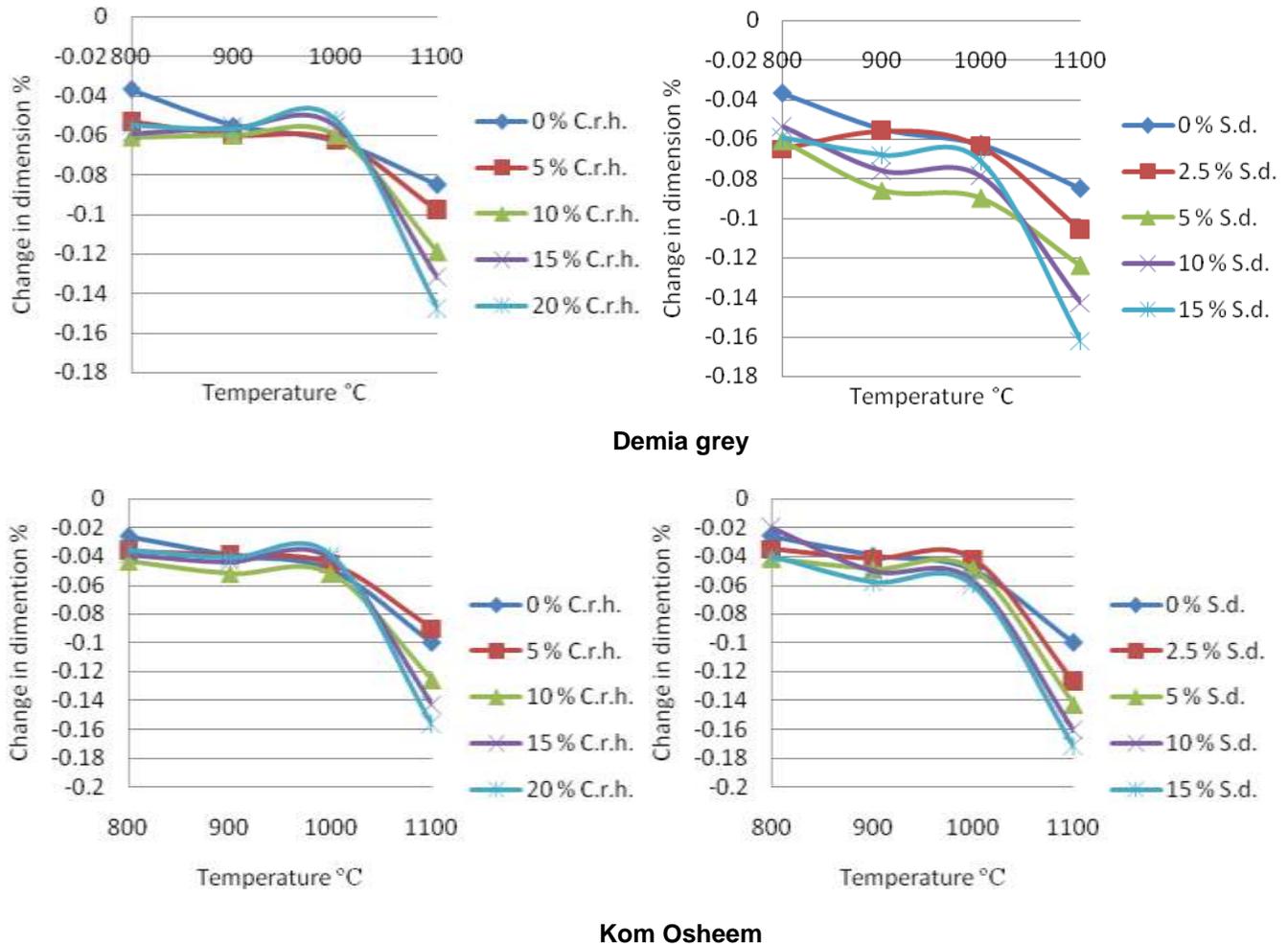
**Figure 7.** Effect of firing temperature on change in dimension % of both additives containing Masakheet, Demia yellow and Kasr El Sagha diatomite specimens.

background of their X-ray diffraction patterns. For this reason, their bulk density increases with increasing firing temperature from 1000 to 1100°C. The fired specimens show also a notable shrinkage in their dimension and a decrease in open porosity. On the other hand, the fired Masakheet, Demia yellow and Kasr El Sagha diatomite specimens contain wollastonite, gehlenite and dicalcium silicate beside unreacted quartz. This means that their phase composition lies in another triangle  $\text{CaO} - \text{SiO}_2 - 2\text{CaO} - \text{Al}_2\text{O}_3 - \text{SiO}_2 - 2\text{CaO} - \text{SiO}_2$  of phase diagram for  $\text{CaO} - \text{Al}_2\text{O}_3 - \text{SiO}_2$  system with higher eutectic point, 1310 to 1318°C. This means less amount of liquid phase was

formed in the specimens fired up to 1100°C. Therefore, their specimens showed nearly no change in their dimension and bulk density on firing them in temperature range of 1000 to 1100°C. This appears more clearly in Kasr El Sagha and Masakheet specimens, where anorthic albite nearly disappears in its X-ray diffraction pattern.

#### Microstructure characteristics

The microstructure developed in the fired diatomite



**Figure 8.** Effect of firing temperature on change in dimension % of both additives containing Demia grey and Kom Osheem diatomite specimens.

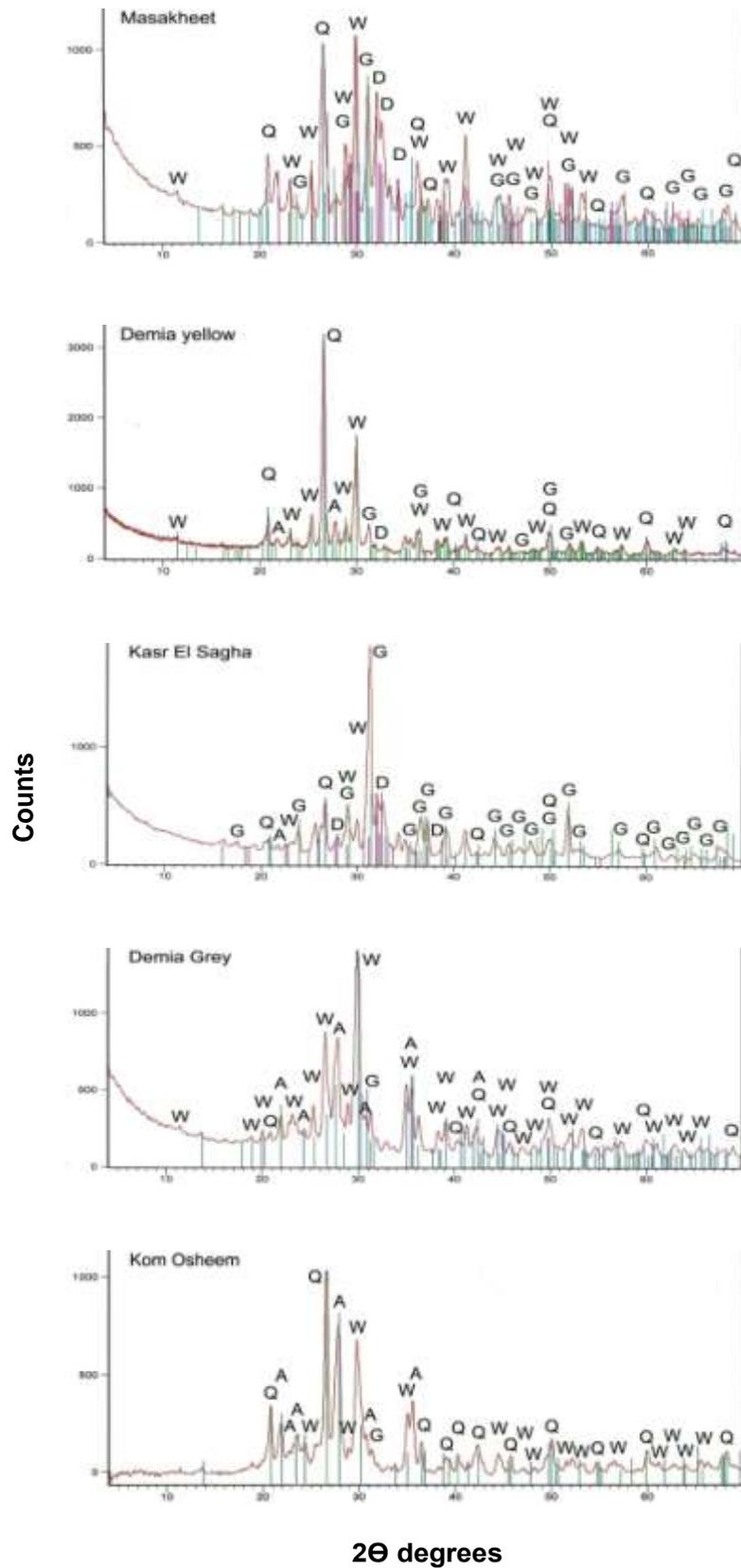
specimens is affected with their chemical composition and the type of employed pore former agent.

Figure 11 shows SEM micrographs of Masakheet, Demia yellow and Kasr El Sagha specimens. These specimens were prepared without using pore former agent and fired for 1h at temperature of 1100°C. As shown, the diatom frustules in Masakheet specimens are mostly preserved and commonly form assemblages. The minute structure of diatom frustules could be clearly seen. The good degree of preservation of diatom shape in this specimen is due to its relatively high purity. Fired Demia yellow specimens contain a significant amount of diatom frustules of elongated shape. The diatom frustules ranged in maximum from 50  $\mu\text{m}$  in length and 25  $\mu\text{m}$  in width. On the other hand, Kasr El Sagha specimen contains minute round grains of < 5  $\mu\text{m}$  diameter. Diatom frustules were hardly detected in this specimen. This is due to the presence of significant amount of calcium carbonate in this specimen. The degree of shape preservation decreases in the diatomite specimens with

increasing impurities content. The impurities react with silica at relatively low firing temperature forming glassy phase.

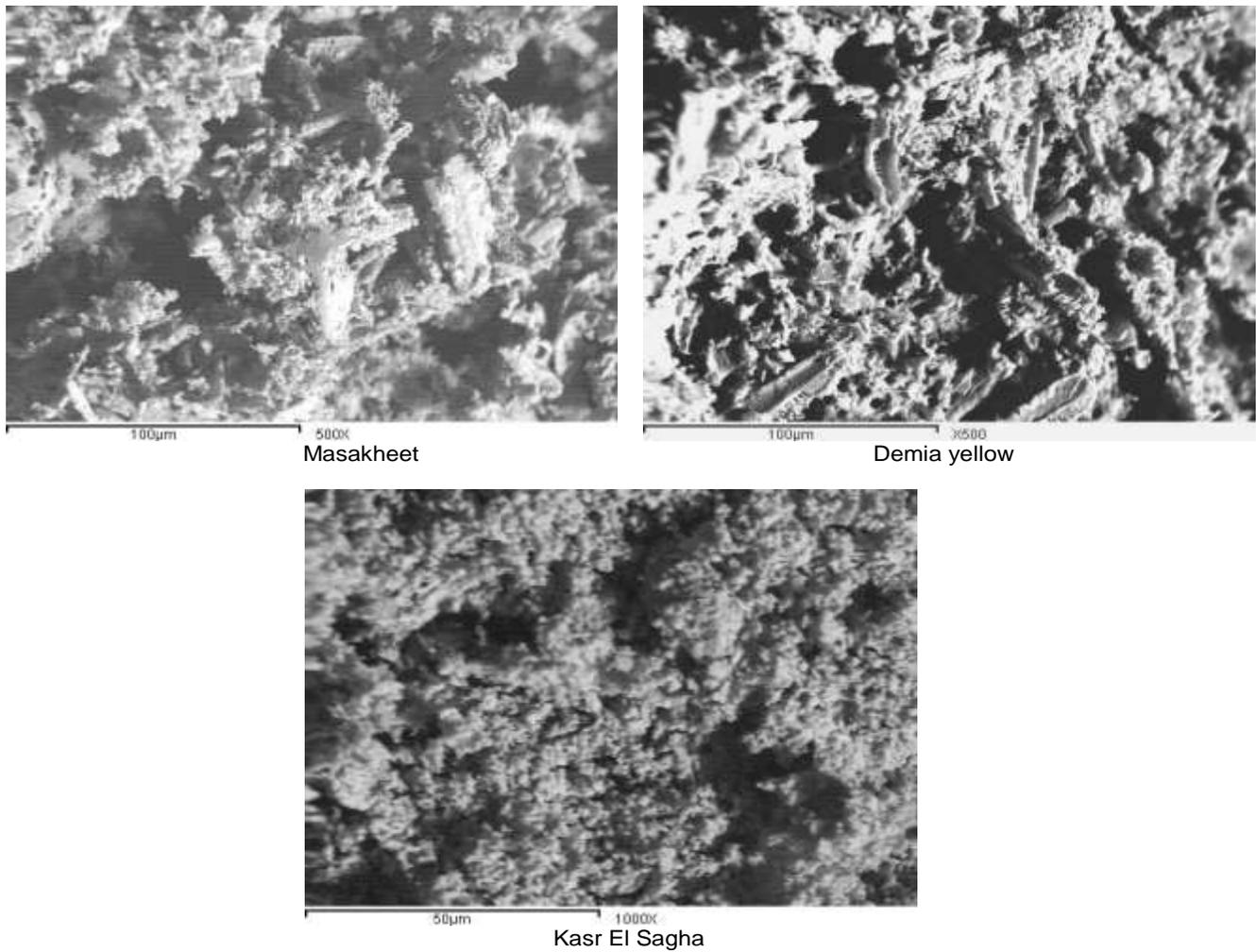
Figure 12 shows SEM micrographs of fracture surface of fired 15 mass %cooked rice hulls and 10 mass % saw-dust containing Masakheet specimens. The bulk density of both specimens are 0.6 and 0.58  $\text{g}\cdot\text{cm}^{-3}$ , respectively. As shown, the pore size can be classified into large pores and minute pores. The large pores of < 50  $\mu\text{m}$  diameter are created from burning out the employed pore former agent. The shape of pores in cooked rice hulls specimens varied from elongated to almost round. The saw-dust specimens have larger and irregular pores exhibiting similar external shape of saw-dust. The minute pores exist in diatom frustules themselves and their amount is effected by the degree of preservation.

Table 2 shows the different properties of some foreign diatomite products as well as some present diatomite specimens. From this table the following remarks are considered:

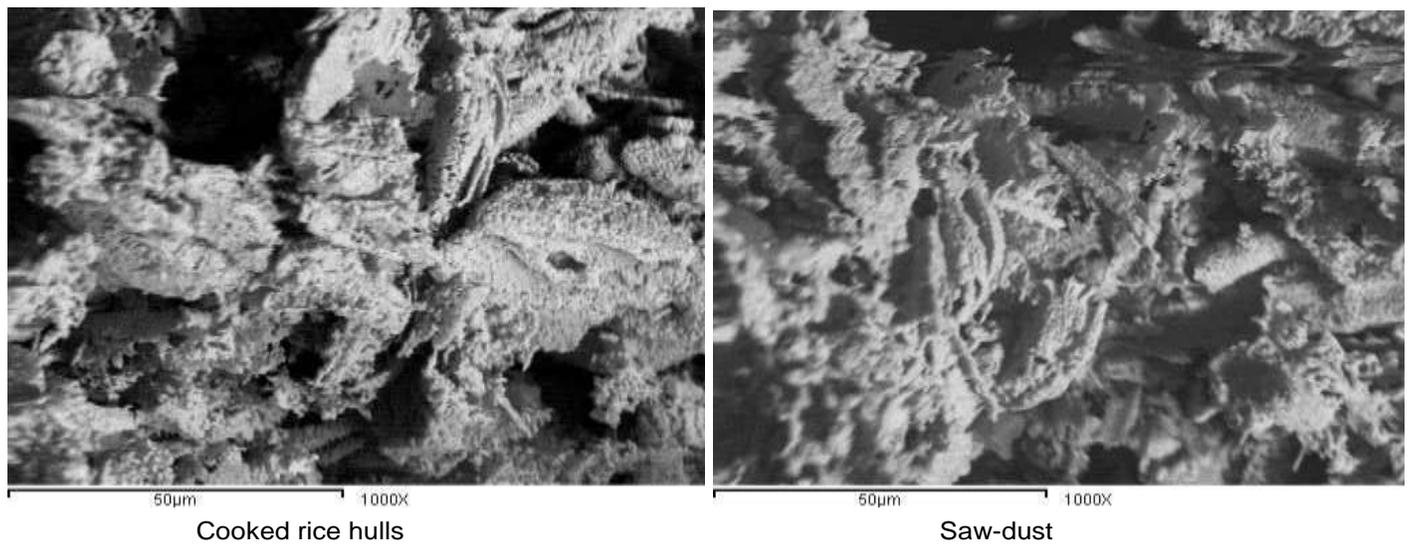


**Figure 9.** X-ray diffraction patterns of the five diatomite specimens fired for 1 h at temperature of 1100°C. A: Albite; Q: Quartz; D: Dicalcium silicate; W: Wollastonite; G: Gehlenite.





**Figure 11.** SEM micrographs of fracture surface of Masakheet, Demia yellow and Kasr El Sagha diatomite specimens fired for 1 h at 1100°C.



**Figure 12.** SEM micrographs of fracture surface of 15 mass % cooked rice hulls and 10 mass % saw-dust containing Masakheet diatomite specimens fired for 1 h at 1100°C.

**Table 2.** Different properties of some foreign diatomite products and the prepared specimens.

Property	Foreign products from Belyakov and Ivanov (2008)			Masakheet		Kasr El Sagha		Demia Yellow
	Russia	Denmark	China	-	With clay	-	With clay	C.R.H. 20% *
Bulk density (g.cm <sup>-3</sup> )	0.5	0.55	0.5	0.68	0.77	0.76	0.79	0.83
Maximum application temperature (°C)	950	900	900	1100				
Compressive strength (Mpa)	2.5	1.4	0.8	0.5	1.4	0.75	1.2	1.37
Permanent linear change (%)	At 950°C < 1	No data	At 900°C < 2	At 1100°C -0.32 -0.46		-0.11	-0.12	-0.55
Open porosity	No data			73.5	70.2	72.3	69.9	65.29
Action of molten aluminium	No sign of penetration or reaction							

\*C.R.H.: cooked rice hulls.

three specimens contain wollastonite, gehlenite and dicalcium silicate.

4. Relatively large amount of glassy phase was formed in Demia grey and Kom Osheem specimens causing an increase in their bulk density.

5. The prepared specimens have bulk density of 0.68 to 0.83 g.cm<sup>-3</sup>, open porosity of 69 to 74, compressive strength of 0.5 to 1.4 MPa and application temperature of 1100°C.

6. The minute pores are preserved with decreasing the impurities content. The shape of macro pores (< 50 µm diameter) is elongated to almost round in cooked rice hulls containing specimens. Pores in saw-dust containing specimens are relatively large and have irregular shape.

#### REFERENCES

- Basta EZ, Abdallah AM, Kadi MB, 1972. Geology and mineralogy of diatomite clay deposits north of Fayoum, Egypt. Faculty of Science Bulletin, Cairo Univ., Egypt, 45:319-329.
- Belyakov AV, Ivanov SÉ, 2008. Advantage of heat insulation made of materials with natural porosity. Refract Ind Ceramics, 49:4300-4301.
- Hassan MS, Ibrahim IA, Ismael IS, 1999. Diatomaceous deposits of Fayium, Egypt: Characterization and evaluation for industrial application. Chinese J Geochem, 18:3233-3241.
- Ibrahim SS, Selim AQ, 2012. Heat treatment of natural diatomite. Physicochem Prob Mineral Proc, 48:2413-2424.
- Kashcheev ID, Popov AG, Ivanov SE, 2009. Improving the thermal insulation of high-temperature furnaces by the use of diatomite. Refract Ind Ceramics, 50(2):98-100.
- Kashcheev ID, Sychev SN, Zemlyanoi KG, Klimovskii AB, Nesterova SA, 2009. Diatomic heat insulation materials with increased application temperature. Refract Ind Ceramics,

50:5354-5358.

- Loukina SM, El Hefnawi MA, Abay Zeed SD, 1994. Mineralogy and geochemistry of diatomaceous earth from Fayium region, Egypt. Mineralogy Society of Egypt, pp: 282-305.
- Tsibin IP, 1966. Replacing fireclay insulant BL-0.8 by diatomite in tunnel kilns and kiln car linings. Refractories, 7:9577. Translated from Ogneupory,10(1966)26-27.
- Yang Y, Zhang J, Yang W, Wu J, Chen R, 2003. Adsorption properties for urokinase on local diatomite surface. Appl Surf Sci, 206(1):20-28.
- Yılmaz B, Ediz N, 2008. The use of raw and calcined diatomite in cement production. Cement Concrete Composites, 30(3):202-211.
- Zalat AA, 2002. An assessment of palaeoecological and palaeoclimatological changes during Holocene of Fayoum depression, Egypt. J Environ Res, Zagzig Univ, pp: 282-305.