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# The Reuse Of Some Solid Wastes For the Manufacture Of Acid-Resisting Bricks

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**ABSTRACT**
The objective of the this work is to study the possibility of making acid resisting bricks congenial to Egyptian market from a clay with partially replaced some Egyptian solid wastes, as a dual target for economic income and environmental pollution protection. This paper is an attempt to use the recycling technique in a useful and available application to our country. Four mixtures, composed of Bashteel clay (BC) and wastes of fine kaolin quarry (FKQW) and waste waterglass, sludge (WGS), were suggested for the study. Articles (ARA) from each mixture composition were prepared then fired at temperatures ranging from 1050oC to 1150oC at 5o/m (firing rate) and 4 hours (soaking time). Moreover, the FKQW was added at constant percentage (25%), while the BC and WGS were added in different percentages ranging from 25-40% and 35-50%, respectively. Finally, to assess the product properties ,the ESS 41:1986 was applied. Consequently, the suitable mixtures design that fulfill this specification were determined, taking into consideration the industrial economy and environmental protection factors. Finally, it was found that the most promising articles which met the Egyptian specification and satisfactory from industrial point of view those were prepared from mixtures M3 at 1100oC and M4 at 1125oC.

## I. INTRODUCTION

It is obvious that hundreds tons of industrial wastes are generated each year throughout Egypt by different industries, producing health, environmental hazards and economical problems. The wide range of industries generates a wide range of industrial by-products that posses different compositions. This results in a broad range of potential waste management options including recycling, recovery and disposal (McDougall et al., 2001). Recycling option is investigated in this work which can be defined according to Williams, 2005 as the collection, separation, clean-up and processing of waste materials to produce a marketable product.

In this work the authors are interested using recycling technique to transform some wastes such as waterglass sludge and fine kaolin quarry waste into a useful product like acid resisting bricks. The advantages of using such recyclable materials are: reducing in using of virgin materials, environmental and economical benefit in terms of decreasing the emission of such wastes to lands and water recourses as well as energy savings in the production process.

The term acid resisting (some times named acid proof) is applied to a non-absorbent (vitrified) brick that has a high crushing strength value as well as high acid resistance (Chesters, 1973). This type of brick is used in the lining of sewage tanks and canals and in structures requiring high resistance to acidic chemical attack.

The acid resisting bricks which are manufactured in Egypt must fulfill the Egyptian Standard Specification (ESS) 41:1986. This specification recorded that this type of brick should have less than 6.0% water absorption and less than 3.5% weight loss due to acid attack as well as compressive strength of more than 300kg/cm2.

The present study is an attempt to make acid resisting bricks from an Egyptian clay with a partial replacement by solid wastes via studying four suggested mixtures. This end product is proposed to be competent to the Egyptian market which always needs this type of brick in sewage systems, especially in the new cities within new urban communities.

## II. MATERIALS AND TECHNIQUES

The materials used in this study are Bashteel clay (BC), and wastes of waterglass (WGS) with fine kaolin quarry (FKQW). The BC was collected from the clay deposits around Bashteel village (Giza governorate). The used clay sample is composed of yellowish, compact and salty clay stone. Due to presence of halite mineral (visual inspection), this deposit is not preferable in clay bricks manufacturing. The waterglass sludge is produced as a residue of the waterglass industry and has to be disposed off . It was taken from the Egyptian salt and

soda company (Kafr El-Zayat city). The fine kaolin quarry waste was supplied by Sinai for Manganese Company (Abu-Zeinema city, South Sinai, Egypt).
The texture and nomenclature of BC sample were described after determining their particle size distribution applying sieving and sedimentation processes according to the American Standards for Testing and Materials (ASTM) D422-63 (2000) as well as the adoption of Picard's method (1971) for graphical representation.
The chemical composition of the studied materials was determined by using the computerized X-ray fluorescence (Phillips, PW 1400 Spectrometer, Holland). The mineralogical composition was executed by using X-ray diffraction technique (Phillips, PW 1373 Vertical Diffractometer, Holland). This analysis was run at 40 kV and 40mA using Cu Kα radiation. The identification of minerals was achieved by using MPDF, 1998. Furthermore, the mineralogical and dehydration information of the studied clay sample were gained through the differential thermal (DTA) analysis by using the thermal analyzer DT 50 (Schimadzu Co., Kyoto, Japan).

## III. MIXTURE DESIGN AND ARTICLE PREPARATION

Four innovated mixtures, namely M1, M2, M3 & M4, were designed for this study. These mixtures are composed of a fixed percentage of fine kaolin quarry waste (25%) as well as addition to 25 up to 40% BC at the expense of WGS which gradually increases from 35% in M4 to 50% in M4 as illustrated in Table (1). These starting materials were crushed then separately ground in a laboratory ball mill and screened to pass 90μm sieve.
The suggested four mixtures were molded in articles of 5cm-side length cube by pressing under 225 kg/cm$^2$. Mixing the composition of the mixtures was performed on dry basis with spraying 5% water by weight before molding. The prepared articles were fired at different firing temperatures ranging from 1050$^o$ to 1150$^o$C at 5$^o$C/m firing rate and 4 hours soaking time.
Physical and mechanical characteristics of the fired articles (ARA) from each mixture were determined and assessed according to ESS 41:1986. Moreover, firing weight loss and firing volume change properties were determined and calculated based on ASTM C67-1999a (2000) and Youssef (2005), respectively. Accordingly, the successful mixtures will be determined for using as acid resisting bricks.

## IV. RESULTS AND DISCUSSION

### 4.1. Characteristics of the Raw Materials

Based on the particle size distribution, of BC sample is considered as well-sorted and very fine clay stone type. Also, it includes about 8.8% fine sand (250-63μm), 12.2% silt (63-2μm) and 79.0% clay (< 2μm).
Table (2) summarizes the chemical constitution of BC as well as FKQW and WGS samples. It is evident that BC is of low-grade type. It contains high $SiO_2$ and $Fe_2O_3$ contents with low $Al_2O_3$ as well as minor $Na_2O$, MgO, CaO and $K_2O$ in decreasing order of abundance. Also, it contains some $SO_3$ and high $Cl^-$ and $SO4^{--}$ ions. This is confirmed by the presence of halite (NaCl) mineral, as shown from the XRD patterns of BC powder sample in Fig. (1). Furthermore, this pattern reflects the occurrence of quartz, feldspar, gypsum and halite as non-clay minerals. Also, XRD patterns of the untreated, glycolated and heated clay fraction of this sample indicate that it is mainly composed of montmorillonite, kaolinite and illite clay minerals in descending order of abundance. This clay mineral composition is characterized by an intense endothermic peak at 104$^o$C due to the removal of its interlayer water as shown on the DTA curve of BC sample in Fig. (2). This is followed by a weak endothermic peak at 242$^o$C and intense one as endothermic reaction peak at ~ 524$^o$C. These refer to the dehydration of goethite [FeO(OH)] mineral and to the dehydroxylation of clay minerals (Smykatz-Kloss,1974), respectively.
The chemical and mineralogical composition of FKQW and WGS samples are identified from their chemical analysis data in Table (2) and XRD patterns in Fig. (3). It is found that the FKQW is composed predomanty of kaolinite [$Al_2(Si_2O_5)(OH)_4$] and quartz [$SiO_2$] minerals and subsidiary of gypsum [$CaSO_4.2H_2O$] and calcite [CaCO3] minerals. Hence, its chemical analysis data shows a major content of $SiO_2$ , $Al_2O_3$, and a minor one of CaO, $SO_3$ and $TiO_2$ in descending order as well as a relatively high content of SO4¯¯ion. On the other hand, WGS sample is rich in $SiO_2$, $Na_2O$ and CaO with some $Al_2O_3$, $Fe_2O_3$ and MgO. These oxides exist as major quartz [$SiO_2$] mineral in addition to minor phases of stilbite [$Ca_2Al_5Si_{13}O_{36}(14H_2O)$], gonnardite [$CaNa_4Si_6Al_4O_{20}(7H_2O)$] and ussingite [$Na_2AlSi_3O_8(OH)$]. Furthermore, as clarified from the chemical composition of the materials used that the fired articles from different mixtures may give constituents that fall within the ternary phase diagram of $SiO_2$-$Al_2O_3$-CaO.

### 4.2. Mineralogy of the Fired Articles

It is valuable here to observe that M4 articles are densified on firing up to 1125$^o$C without any changes in their shape due to partial melting. While, M3 and M2 articles are densified up to 1100$^o$C and 1075$^o$C, respectively and those of M1 are densified only at 1050$^o$C. The shape of these articles suffer from shape changes above these temperatures due to their melting and over firing. This is mainly attributed to the high content of the alkali oxide, $Na_2O$, in the fired mixtures from M4 to M1 (11.80 – 14.38%) as demonstrated in Table (3). From this table, it is evident that the increase of WGS from M4 to M1 mixtures at the expense of BC content is concurrent with the increase $Na_2O$ content. This construe the lowering of partial melting temperature in the same trend of WGS increment.

Table (3) also illustrates a little increase in $SiO_2$ content from 59.20 (M1) to 59.27% (M4) with simultaneous decrease of CaO content from 6.64 to 5.80% due the gradual increase of WGS addition at the cost of BC from M4 to M1. Moreover, $Al_2O_3$ content increases with increasing of BC content from M1(14.74%) to M4 (16.45%) mixtures. Meanwhile, the $Fe_2O_3$, MgO and $K_2O$ contents exist at more or less constant levels of 3.13, 2.36 and 0.37%, respectively. These data indicate that on decreasing WGS from M1 to M4 leads to somewhat gradual decrease in C/S molar ratio (basicity) from 0.12 to 0.10.

Figs. (4 – 6) exhibit the XRD patterns of the standing articles from the four proposed mixtures that fired at $1050^o$, $1075^o$, $1100^o$ &$1125^oC$. From these patterns, at $1050^oC$ the detected phases are anorthite [(Ca,Na)$(Si,Al)_4O_8$), augite [ca $(Fe,Mg)Si_2O_6$], α-wollastonite [$CaSiO_3$], gehlenite [$Ca_2Al_2SiO_7$], and quartz [$SiO_2$]. These phases are in concordance with neomineralization of El-Mahllawy (2004). On increasing firing temperature up to $1075^oC$ in M2, up to $1100^oC$ in M3 as well as up to $1125^oC$ in M4, significant increase in the amount of anorthite, which has lower C/S ratio (0.25) occurs with gradual diminishing of phases having higher C/S ratio; namely augite (0.5), gehlenite (2.0) and wollastonite (1.0).

It is evident from these patterns that the quartz, gehlenite and wollastonite minerals decrease with the increase of firing temperature. the contrary, anorthite mineral increase with the increase of firing temperature. This is attributed to the fact that, when the temperature increases to $800^oC$, $CaCO_3$ is decomposed to CaO and the latter reacts with quartz and Al, Si of the clay and leads to formation of wollastonite and metastable gehlenite (Tjerk, 1970). By Further increase in temperature, the gehlenite content diminishes in intensities and augite appears (Jordan et. al, 2001). This is attributed to the fast that the gehlenite mineral reacts with quartz to give wollastonite and plagioclase (Gonzalez-Garcia et. al, 1990). On the other hand, the decreasing in the wollastonite content with the increase of firing temperature is in contradiction with Gonzalez-Garcia et. al (1990), and this may be ascribed to the deficiency in the CaO in the raw materials which leads to the presence of augite at the expense of wollastonite formation. The presence of anorthite in the XRD patterns of the fired articles demonstrates that the firing process has reached the equilibrium state giving evidences that reaction is completed.

### 4.3. Physical and Mechanical Properties of the Fired Articles

Table (4) represents the standing and melting articles (ARA) of the four suggested mixtures as a function in firing temperatures. The properties of these standing fired articles according to ESS 41:1986 are listed in Table (5). From these properties, the following is noticed:

-The water glass sludge content plays an important role in the obtained properties. Where, the water absorption values, weight loss due to acid attack and compressive strength values fulfill the ESS 41:1986 at relatively low firing temperatures with the increase in water glass sludge content. This is attributed to the increase of glassy phase formation which closes the open pores (Searle, 1953), where the WGS includes a high content of alkalis that work as a fluxing agent.

-The water absorption and weigh loss, by acid attack, values decrease with the increase of firing temperature. This is presumably due to the increase of open pore closing, as well as the increase in the formation of more acid withstanding phase (anorthite). Furthermore, porosity which reflects a water absorption property values is a major component that influences strength, durability, shrinkage and creep properties of materials (O'Farrel et. al, 2004).

-The compressive strength values increase with the increase of firing temperature. This may be attributed to the increase of articles densification by development of liquid phase as revealed from the values of firing weight loss and firing shrinkage properties. Also, these values increase with the increase of WGS, and this refers to the increase of glassy phase formation which convoys the increase in WGS. Thereby, if glassy phases are occurred, not more than necessary, the fired body becomes strong and compact.

-The weight loss and volume shrinkage percentage of the fired articles increase with the increase of waterglass content as well as firing temperature and also with the decrease of Bashteel clay raw material. This may be referred to including of WGS on a high content of volatile alkalis which their releasing is augmented with increase firing degree increasing.

The increase of articles melting at low firing temperatures is noticed with the increase of WG sludge content. This is due to the WGS has a high content of alkalis which work as a fluxing agent. Too large proportion of fluxes in the fired body is one of the primary causes of increasing the fusibility and premature failure of some bricks at lower degrees of temperature (Doremus, 2003).

-The fired articles from all mixtures which satisfactory to achieve the limits of ESS 41:1986 are:

M1 at 1050°C, M2 at 1075°C, M3 at 1075°C &1100°C and M4 at 1125°C.

## V. QUALITY ASSESSMENT

As shown from the visual inspection of the successful fired articles (ARA) which meet the ESS 41:1986, they have a brown color, smooth surfaces, sharp ends and faces free from any type of cracks.
Table (6) manifests a debate between the properties obtained from the most distinctive articles from our study with others. From this debate, it is clear that the articles which are prepared from the most promising mixture (M3 at 1100°C) has a brilliant achievement for the ESS 41:1986 than the others.

## VI. CONCLUSION

From the above findings, the following primary conclusions can be drawn from the work:

1- The increase of water glass sludge plays an important role in the enhancement of the fired article properties at relatively low firing temperatures.
2- The articles of mixtures that fulfill the Egyptian Specification 41:1986 are: M1 at 1050°C, M2 at 1075°C, M3 at 1100°C and M4 at 1125°C
3- Articles of mixtures M3 and M4, fired at 1100°C and 1125°C, respectively are the most applicable and comparable ones satisfying industrial aspects.
4- The proposed laboratory acid resisting articles are congenial for the Egyptian market, where the authors used waste materials (inexpensive if compared with the ordinary mixture of sand, feldspars and other additives), and without any further expensive treatment and are prepared under the lowest normal conditions of moulding pressure, firing rate, soaking time and firing temperature.
5- The addition of 35-50% waterglass sludge at the expense of Bashteel clay and fine kaolin quarry waste increases alkalis oxide contents. This decreases the temperature of densification by the developed liquid phase to 1050°C.
6- The fired articles that are mainly composed of anorthite mineral show minimum water absorption loss due to acid attack as well as maximum compressive strength.
7- Utilization of the studied wastes in the production of high quality acid-resisting bricks achieves their environmentally safe disposal, production of useful products with high quality at low firing temperatures and saving our virgin inventory of natural feldspar minerals, which usually uses as fluxing materials in such production.

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**Table (1): Suggested mixtures composition, %**

| Symbol | Composition (%) | | |
|---|---|---|---|
| | **Fine kaolin quarry waste (FKQW)** | **Bashteel clay sample (BC)** | **Water glass sludge (WGS)** |
| M1 | 25 | 25 | 50 |
| M2 | 25 | 30 | 45 |
| M3 | 25 | 35 | 40 |
| M4 | 25 | 40 | 35 |

**Table (2): Chemical composition of the materials used**

| **Oxide content %** | **Bashteel clay sample (BC)** | **Fine kaolin quarry waste (FKQW)** | **Water glass sludge (WGS)** |
|---|---|---|---|
| $SiO_2$ | 44.66 | 51.90 | 47.30 |
| $Al_2O_3$ | 12.52 | 26.76 | 4.18 |
| $Fe_2O_3$ | 5.57 | 0.97 | 1.07 |
| CaO | 3.08 | 2.61 | 7.84 |
| MgO | 4.24 | 0.19 | 1.10 |
| $Na_2O$ | 5.76 | 0.18 | 20.18 |
| $K_2O$ | 0.88 | 0.02 | nil |
| $SO_3$ | 2.79 | 2.49 | 0.20 |
| $TiO_2$ | 0.93 | 2.33 | nil |
| $Cl^-$ | 2.90 | 0.14 | nil |
| $SO_4^{--}$ | 2.20 | 1.95 | nil |
| L.O.I | 19.26 | 12.63 | 17.95 |

**Table (3): Mixture as well as chemical Composition of the fired mixtures on calcined basis**

| **Mixture** | **Mixture composition, %** | | | **Chemical composition on calcined basis, %** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **$SiO_2$** | **$Al_2O_3$** | **$Fe_2O_3$** | **CaO** | **MgO** | **$Na_2O$** | **$K_2O$** | **C/S m.ratio** |
| M1 | 25 | 25 | 50 | 59.20 | 14.74 | 2.70 | 6.64 | 2.06 | 14.38 | 0.28 | 0.12 |
| M2 | 25 | 30 | 45 | 59.22 | 15.31 | 2.98 | 6.36 | 2.26 | 13.53 | 0.34 | 0.12 |
| M3 | 25 | 35 | 40 | 59.25 | 15.88 | 3.27 | 6.08 | 2.46 | 12.66 | 0.39 | 0.11 |
| M4 | 25 | 40 | 35 | 59.27 | 16.45 | 3.57 | 5.80 | 2.67 | 11.80 | 0.45 | 0.10 |

**Table (4): Standing (√) and melting (X) articles of the suggested mixture at different firing temperatures.**

| Firing temp. °C | Mixture | | | |
|---|---|---|---|---|
| | M1 | M2 | M3 | M4 |
| 1050 | √ | √ | √ | √ |
| 1075 | X | √ | √ | √ |
| 1100 | X | X | √ | √ |
| 1125 | X | X | X | √ |
| 1150 | X | X | X | X |

**Table (5): The average properties of the standing fired acid resisting articles of different mixtures.**

| Mixture | Firing temp. °C | Water abs. % | Acid weight loss % | Comp. strength kg/cm² | Firing weight loss | Vol. shrink age % |
|---|---|---|---|---|---|---|
| M1 | 1050 | 1.00 | 0.03 | 670.00 | 14.00 | 9.05 |
| M2 | 1050 | 11.82 | 3.50 | 530.00 | 5.02 | 6.29 |
| | 1075 | 0.09 | 0.49 | 902.00 | 16.06 | 11.60 |
| M3 | 1050 | 16.62 | 5.33 | 490.00 | 2.64 | 5.04 |
| | 1075 | 5.85 | 1.50 | 530.00 | 10.08 | 9.81 |
| | 1100 | 0.77 | 0.16 | 802.00 | 13.46 | 14.64 |
| M4 | 1050 | 19.43 | 8.56 | 372.00 | 1.67 | 3.87 |
| | 1075 | 14.81 | 2.05 | 452.00 | 2.72 | 6.24 |
| | 1100 | 6.55 | 1.21 | 572.00 | 8.43 | 10.32 |
| | 1125 | 1.25 | 0.67 | 724.00 | 11.83 | 13.19 |
| ESS 41:1986 | | <6.0 | <3.5 | >300 | --- | --- |

**Table (6): A comparison between properties of acid resisting bricks produced under oxidizing firing condition and the present articles from the most promising mixture (M3 at 1100°C)**

| Produced by | Properties | | |
|---|---|---|---|
| | Water absorption % | Weight loss by acid attack % | Compressive strength |
| Attia et al., 1994 (Egypt) | 5.36 | 1.84 | Not Determined |
| KEPCO Co., 2006 (Egypt) | 3.8 | 2.80 | 660.00 |
| Sowelam Co., 2004 (Egypt) | 4.20 | 3.00 | 350.00 |
| El-Mahllawy, 2004 (Egypt) | 0.35 | 2.00 | 561.00 |
| El-Mahllawy, 2005 (Egypt) | 1.59 | 0.96 | 910.00 |
| Present study, 2006 (Egypt) | 0.77 | 0.16 | 802.00 |

**Fig. (1)XRD patterns of BC powder sample .**

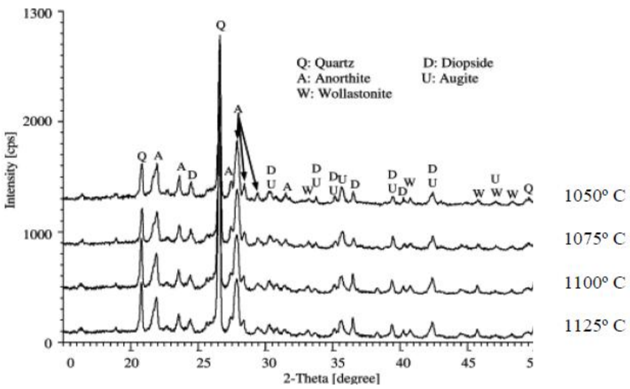


**Fig. (2) DTA curve of BC sample**

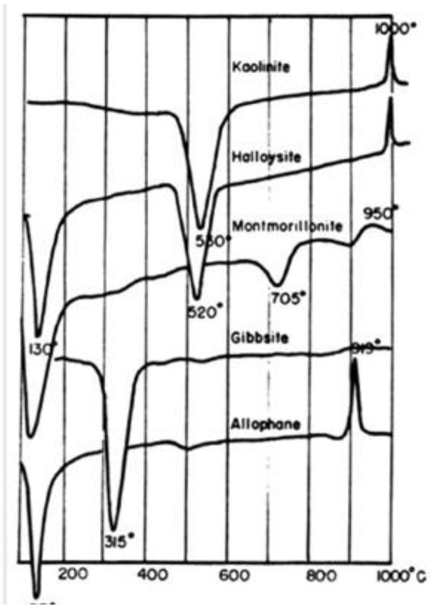


**Fig. (3) XRD patterns of the chemical and mineralogical**

**composition of FKQW and WGS samples .**

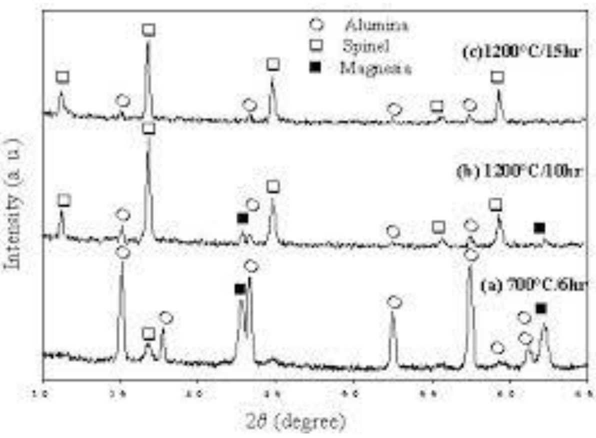


**Fig. (4)**

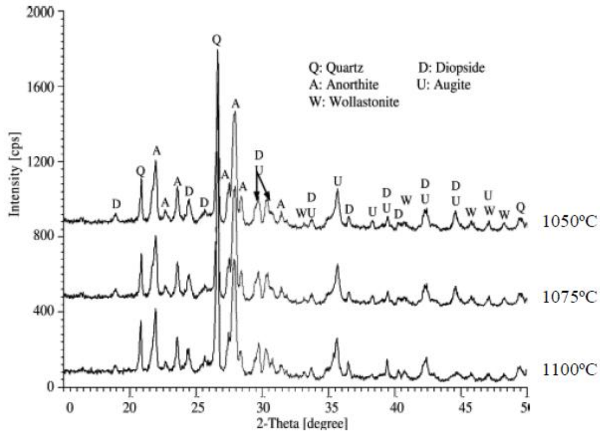


**Fig. (5)**

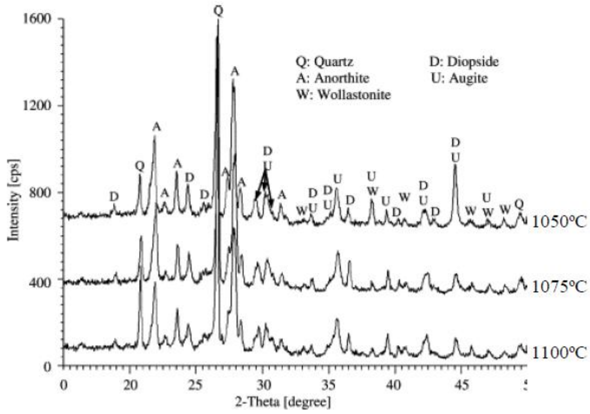


**Fig. (4, 5, 6) XRD patterns of the standing articles from the four proposed mixtures that fired at 1050o, 1075o, 1100o & 1125oC**