# RECYCLING OF LANDFILL WASTE IN THE MANUFACTURE OF BUILDING BRICKS

K.A. El–Naggar, Sh.K. Amin, M.M. Ahmed, M.F. Abadir

**Abstract—** A landfill solid waste obtained from a location in Delta region –Egypt was used in the manufacturing of fired clay bricks by blending with clay, as eco friendly waste recycling process. This affords utilizing a priceless waste while simultaneously minimizing pollution. Raw materials were characterized for their chemical and mineralogical composition using XRF and XRD respectively; the particle size distribution of both clay and waste was assessed by sieving. Mixtures were prepared by blending up to 35% waste with clay. Brick specimens for each mixture were molded, dried then fired. Tests performed on the wet mixes showed that waste addition caused a slight decrease in plasticity up to about 20% addition. Also the dry compressive strength was almost unaffected by the addition of waste up to 25% addition. On firing for 3 hours at temperatures ranging from 700 to 850 °C the percent boiling water absorption as well as apparent porosity regularly increased on waste addition associated with a decrease in bulk density and hence the weight of produced bricks. One remarkable feature was the elevated compressive strength obtained on adding up to 20% waste and firing at 800 °C (25 – 30 MPa) that exceeded by far the standard requirements for normal duty clay bricks according to ASTM C 62/2013 (8.6 MPa).This was interpreted in the light of formation of diopside and anhydrite that confer high mechanical properties to the fired body. Firing at higher temperatures besides being less economical caused excessive black core formation resulting in bursting of the bricks for waste addition exceeding 10%. It was concluded that the replacement of 10 – 15  wt. % of clay by the dump solid waste site and firing at 700 °C, improved brick quality as well as contributing to minimize pollution.

**Index Terms—** Landfill – Waste Recycling – Fired Clay Bricks – Standards of Building Bricks.

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## 1  INTRODUCTION

Brick making is an important industry in many parts of the world. It is an activity that can take place in many forms, in large modern factories to small rural businesses. Although the process is simple, brick manufacturing still follows the following basic steps: Mixing clay with water and some minor ingredients, molding, drying and firing at temperatures in the 800–1000 °C range.

Owing to the flexibility of the brick composition, different types of waste have been successfully incorporated into fired clay bricks by previous researchers, even in high percentages [1; 2]. The most commonly used wastes are various types of fly ash [3], sewage sludge [4], sawdust [5], kraft pulp residue [6], recycled paper [7], polystyrene [8], processed waste tea [9], cigarette butts [10], rice hulls and husk [11], rice straw [12], phosphogypsum (waste used by phosphoric acid plants) [13]), cement dust (a waste produced by the cement industry) [14] and many other domestic and industrial wastes. The utilization of these wastes usually helps reducing the negative effects of their disposal. However, the potential wastes can only be recycled if the properties and the environmental pollutant of the new manufactured brick meet the specific requirements and comply with the relevant standards.

- *K.A. El Naggar, and M.F. Abadir, Chemical Engineering Department, Faculty of Engineering, Cairo University.*
- *Sh.K. Amin, Chemical Engineering and Pilot Plant Department, Engineering Research Division, National Research Centre, 33 El Bohouth St. (Former El Tahrir St.), Dokki, Giza, Egypt, Affiliation ID: 60014618, PO box 12622, Dokki, Giza, Egypt, E–mail: dr.shereenkamel@hotmail.com; sheren51078@yahoo.com.*
- *M.M. Ahmed, Faculty of Engineering, Matareya University, Egypt.*

On the other hand, the problem of municipal solid waste disposition through dump–filling has become a major environmental threat in Egypt in the last few years. The amount of municipal solid waste increased from 10 to about 20 million tons per year from 2000 to 2010 [15, 16]. Of these, only 9% is composted, 5% landfilled and 2.5% recycled. The rest is either simply dump–filled.

The aim of this paper is to use dump–filled waste without any pretreatment in the production of clay bricks.

## 2 MATERIALS AND METHODS

The two raw materials used are: Desert clay used in the manufacture of clay bricks and landfill waste. Both were obtained from the Benisuef region, 100 km South of Cairo.

Both materials were screened to assess their particle size distribution. A Tyler standard screen set was used equipped with an electric shaker. The screen apertures varied from 5 mm down to 44 µm. Samples of each material were analyzed for their mineralogical composition using analyzed by a BRUKUR D8 advanced computerized X–Ray Diffractometer apparatus. The chemical analysis of each was determined by XRF using a Philips Diffractometer type PW 1730. Thermal analysis was used to follow up the decomposition and oxidation behavior of the raw materials by combined DTA and TG. The apparatus used was of type Netzsch STA 409 C/CD. The heating rate was kept at 10 °C.min$^{-1}$ in air. The organic matter content in both materials was determined for both materials using the classical method of Walkley [17].

Landfill waste powder was then used to replace part of clay as the basic mixture in the fired clay brick manufacturing, in percentage of weight starting from 0 % till 40 %, increasing by 5 %. This way, eight mixtures were prepared. These mixtures were mixed on dry basis for 10 minutes each. Plasticity of water mixed pastes was determined by the Pfefferkorn method [18].

Brick samples were prepared in the following way: Cubic brick specimens of approximate dimensions (50 × 50 × 50) mm³ were molded by dry pressing using a laboratory hydraulic press under uniaxial pressure of 15 MPa using 20% water. Brick specimens were then dried on three steps using a laboratory dryer. The first step was at 50 °C for 24 hours, then at 80 °C for three hours, then at 110 °C for another three hours. Each brick sample consisted of three specimens for each mixture. The linear shrinkage of unfired brick samples was measured according to ASTM standard [ASTM C 326 / 2009 (2014)]. The green compressive strength was determined using a UTM machine in accordance with ASTM C 67 / 2014.

Brick specimens were then fired using a laboratory furnace Protherm–electrical furnace model PLF 14015, at four different temperatures (700 °C, 750 °C, 800 °C, and 850 °C), for one hour soaking time with a total firing time is 3 hours. Heating rates were chosen to be as close as possible to industrial conditions. Firing shrinkage was determined according to ASTM C 326 / 2009 (2014), while boiling water absorption was calculated in accordance with ASTM C 67 / 2014. The apparent porosity and bulk density were determined according to ASTM C 373/2014. The compressive strength of fired bricks was determined in a way similar to that of unfired green bricks (ASTM C 67 / 2014). SEM and EDAX were occasionally used to disclose the phase composition and microstructure of fired specimens. A JEOL – JMS 6510 model SEM and a TEAM DES EDAX analyzer were used to that effect.

## 3 RESULTS AND DISCUSSION
### 3.1 Assessment of Raw Materials
#### 3.1.1 Chemical analysis

Table (1) shows the average composition of both waste and clay as obtained from XRF analysis.

The high loss on ignition of waste material (at 1000 °C) is due to the high content of organic compounds as well as the elevated percentage of calcium some of which being present as carbonate which dissociates on heating to 1000 °C. This was assessed by determining the organic matter content of waste which was found to equal 27.46%, a result confirming the previous conclusions. It was also found that the organic matter content of clay amounted only to 1.52%.

The determination of free silica in both materials showed that its percentage in waste was about 15.5% in the waste and about 22% in clay.

#### 3.1.2 Mineralogical analysis

XRD traces of clay used showed it to consist of quartz, kaolinite, montmorillonite, calcite and gypsum, a result in agreement with the chemical analysis. On the other hand, the XRD

of waste displayed poor crystallinity and consisted of the following phases: quartz, calcite, albite and anhydrite. This result agrees with its relatively elevated levels of silica and calcium oxide (Fig 1a and 1b).

TABLE 1

AVERAGE COMPOSITION OF RAW MATERIALS

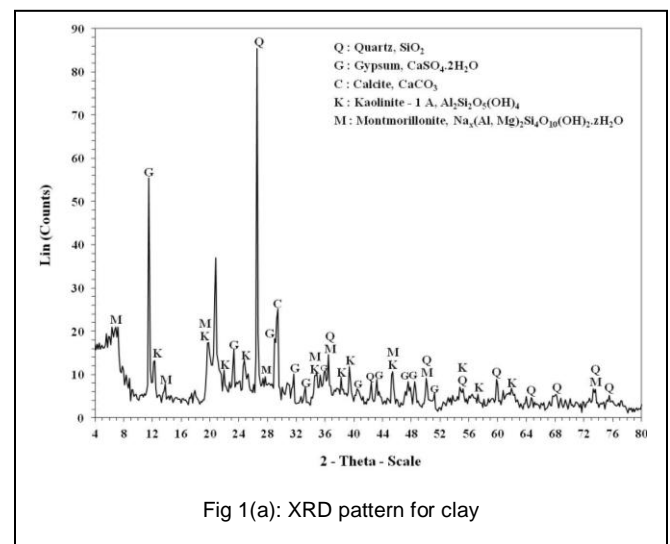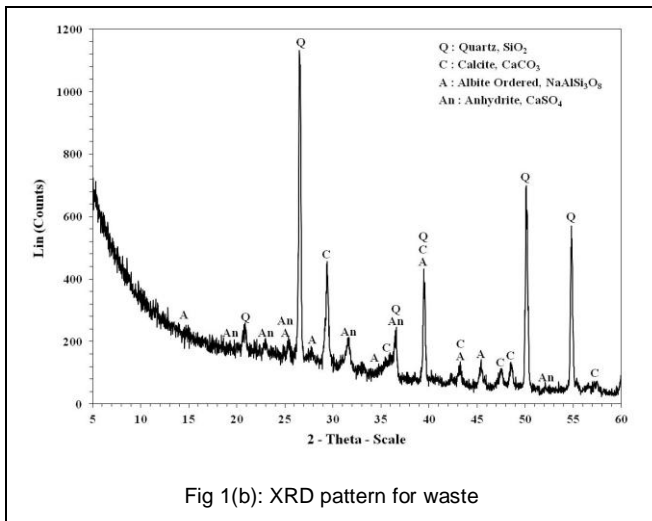| Constituents, Wt. (%) | Waste | Clay |
|---|---|---|
| $SiO_2$ | 23.864 | 39.97 |
| $Al_2O_3$ | 5.308 | 15.03 |
| $Fe_2O_3^{tot.}$ | 10.567 | 8.26 |
| $TiO_2$ | 0.862 | 0.91 |
| MgO | 1.054 | 1.59 |
| CaO | 14.139 | 8.53 |
| $Na_2O$ | 2.993 | 2.22 |
| $K_2O$ | 1.618 | 1.11 |
| $P_2O_5$ | 1.914 | 0.19 |
| $SO_3$ | 2.117 | 6.17 |
| SrO | 0.070 | 0.09 |
| $Cr_2O_3$ | 0.039 | 0.02 |
| MnO | 0.131 | 0.04 |
| $ZrO_2$ | 0.038 | 0.05 |
| $Co_3O_4$ | 0.034 | —— |
| ZnO | 0.362 | 0.02 |
| BaO | 0.140 | —— |
| NiO | 0.017 | 0.01 |
| CuO | 0.139 | 0.01 |
| PbO | 0.075 | —— |
| Cl | 3.514 | 1.11 |
| Br | 0.005 | —— |
| L.O.I | 31.0 | 14.68 |
| **Total** | **100** | **100.01** |



Fig 1(a): XRD pattern for clay

Fig 1(b): XRD pattern for waste

### 3.1.3 Thermal analysis

Results of thermal analysis of the clay used are summarized in Table (2) and reveal peaks corresponding to the decomposition of phases disclosed by XRD analysis.

On the other hand, thermal analysis of waste produced one large endothermic peak associated with 10% loss in weight in the range 50–100 °C corresponding to loss of physical water and volatilization of organic impurities. Subsequently a series of small exothermic peaks followed presumably due to oxidation of the remaining organic materials. A final endothermic peak starting at about 840 °C indicated the decomposition of calcite. The total loss in weight at 1000 °C was 31.45% in agreement with XRF findings.

TABLE 2

THERMAL ANALYSIS OF CLAY

| Peak # | $T_{start}$ °C | $T_{peak}$ °C | $T_{end}$ °C | Transformation |
|---|---|---|---|---|
| 1 | 30 | 54 | 110 | Loss of physical water |
| 2 | 108 | 121 | 155 | Dehydration of gypsum to $CaSO_4.\frac{1}{2}H_2O$ |
| 3 | 208 | 215 | 220 | Dehydration of gypsum to anhydrite |
| 4 | 401 | 472 | 550 | Dehydroxylation of montmorillonite |
| 5 | 595 | 665 | 695 | Dehydroxylation of kaolinite |
| 6 | 785 | 862 | 884 | Calcination of calcite |

### 3.1.4 Screen analysis

The screen analysis of both materials is shown in Fig (2) and clearly reveals that clay is finer than waste. The mean particle size was calculated in each case using the method cited by McCabe et al [22] and found to be 0.187 mm for clay and 0.495 mm for waste.
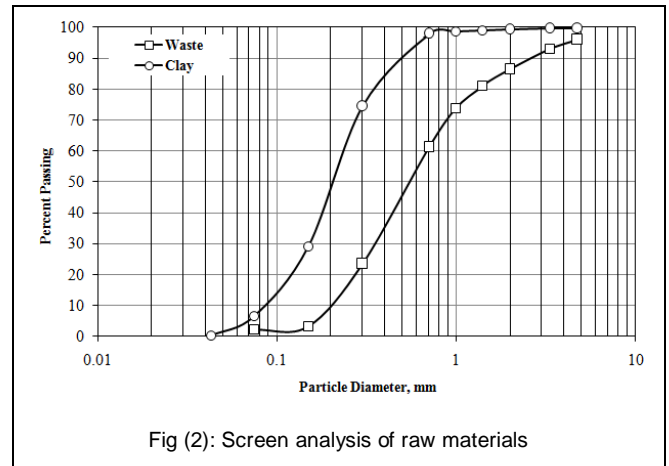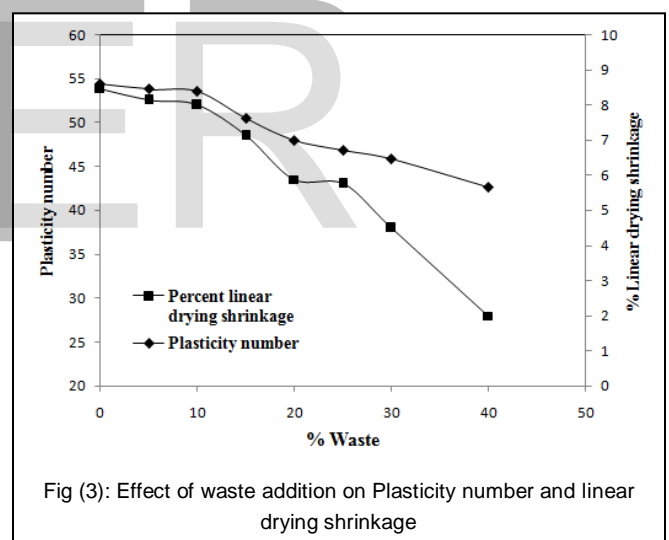
## 3.2 Assessment of Green Bodies
### 3.2.1 Plasticity number

Fig (3) shows the effect of waste addition on Pfefferkorn plasticity number. This latter is obtained by varying the percent water each time and subjecting a standard cylindrical specimen to a standard load. The initial and final heights of

the cylinder being $H_0$ and $H$, the plasticity number is the percent water corresponding to a ratio $H_0/H = 3.3$. This figure shows that there is a slight decrease in plasticity from 54% to 49% as the waste content is increased from 0 to 15%. A sharp drop then follows that takes the plasticity down to 28% at 40% waste. This is due to the non–plastic nature of the waste constituents.



Fig (2): Screen analysis of raw materials



Fig (3): Effect of waste addition on Plasticity number and linear drying shrinkage

### 3.2.2 Linear drying shrinkage

Fig (3) also shows the effect of waste addition on linear drying shrinkage. Two factors are responsible for the decrease in linear shrinkage: First, the non–plastic character of waste components and second, the larger particle size that slows the motion of its particles upon shrinkage. It is seen that the shrinkage curve varies in a similar way to that of plasticity.

### 3.2.3 Dry (green) compressive strength

Although the green strength is not a standard prerequisite for bricks, it is important to determine its value since too low a green strength will cause failure on handling. On adding landfill waste to clay two contradicting factors enter into play as far as green strength is concerned: First, the non organic con-

stituents of that waste possess elevated compressive strengths as revealed in Table (3) [23]. This will definitely add to the green strength of clay. On the other hand, the non plastic nature of this waste coupled with its elevated particle size will decrease drying shrinkage thereby lowering the green strength owing to poor compactness on shrinkage.

The effect of these two factors is made apparent by considering the effect of waste addition on green strength illustrated in Fig (4). On adding waste to clay in relatively moderate proportions (< 25 %) the effect of the elevated strength of inorganic constituents clearly appears as the green compressive strength is almost constant ranging from 3.8 to 4.8 MPa. Past that addition level, the effect of low shrinkage primes, as more pores are thus formed, and the strength drops to about 2.2 MPa at 35 % addition. The values obtained for addition levels < 25 % were comparable to those of plain clay bricks and guaranteed safe handling of dry bricks.

TABLE 3

COMPRESSIVE STRENGTH OF INORGANIC CONSTITUENTS OF WASTE [23]

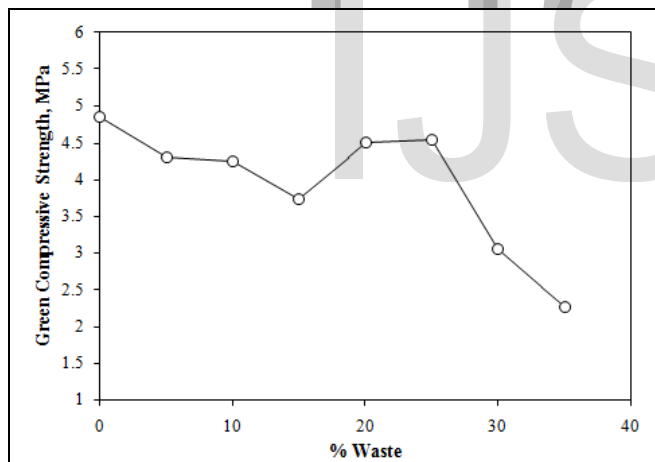| Compound | Quartz | Calcite | Albite | Anhydrite |
|---|---|---|---|---|
| Strength, MPa | 150 – 300 | 70 – 80 | 85 – 95 | ~ 70 |



Fig (4): Effect of waste addition on green compressive strength

## 3.3 Assessment of Fired Bodies

As already pointed out, the chosen firing temperatures were 700, 750, 800 and 850 °C which are lower or equal to those used in industry. The dry bricks were fired in a prescheduled manner so as to take into consideration the different losses occurring on firing as obtained from thermal analysis.

The firing schedule was as follows: The temperature was increased from room temperature to 300 °C, for 30 minutes, then from 300 °C to 600 °C, (increasing 100 °C every 30 minutes, in order to provide slow escape of combined water and prevent crack formation). The temperature was finally increased from 600 °C to the maximum firing temperature, fixing that temperature for one hour.

### 3.3.1 Boiling water absorption

Fig (5) illustrates the effect of waste addition on boiling water absorption. The addition of waste increases water absorption owing to the coarser particle size of waste. On the other hand the values of water absorption are comparable on firing at 700 and 800 °C where as they are lowest at 750 °C. The interpretation of that result is as follows: At 700 °C, there is little shrinkage and so, pores are available for diffusion of water. On raising the firing temperature to 750 °C, higher shrinkage is observed consequently decreasing water absorption. Finally at 800 °C, the decomposition of calcium carbonate not only leaves room for water diffusing in pores but also enhances absorption of water to cause slaking of the produced calcium oxide according to the reaction: $CaO + H_2O = Ca(OH)_2$. Brick samples fired to 850 °C showed extremely high values of water absorption due to the formation of apparent cracks as illustrated in Fig (6) that displays a specimen containing 20% waste fired at 850 °C. It is believed that the rapid calcination of calcium carbonate is responsible for that effect.
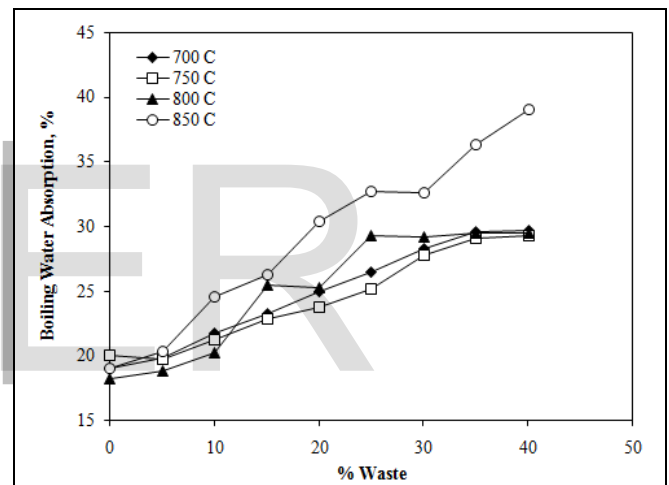


Fig (5): Effect of waste addition on boiling water absorption



Fig (6): Apparent crack formation in sample containing 20% waste fired at 850°C

### 3.3.2 Apparent porosity

When the apparent porosity was plotted against the percent waste a series of curves showed up that produces the same trend as those of boiling water absorption. This result is expected as most pores at the firing temperatures investigated are of the open type (Fig 7). A consequence of increased porosity on adding waste is the decrease in bulk density observed (Fig 8). This may also be due to the fact that waste has a lower density than clay: determination of the true density of clay showed it to equal 2.38 g/cm³ while that of waste = 1.83 g/cm³.

Fig (7): Effect of waste addition on apparent porosity

Fig (8): Effect of waste addition on bulk density
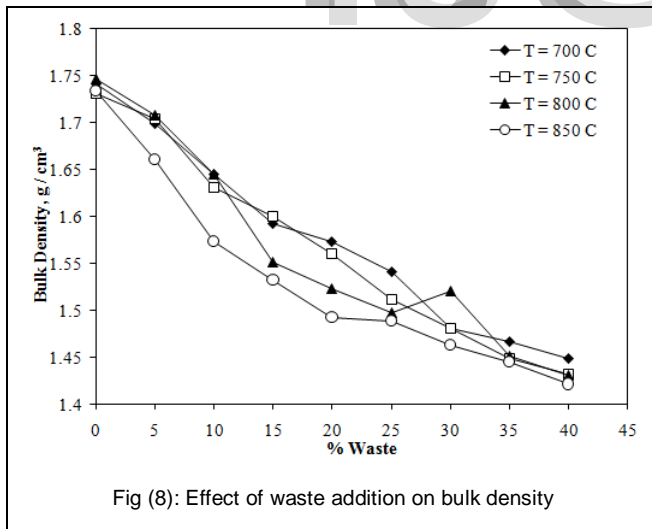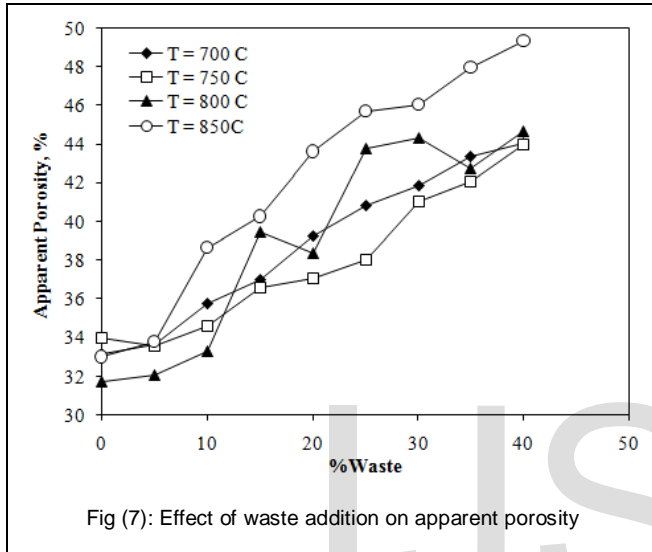
### 3.3.3 Compressive strength

This is by far the most important property required by international standards and locally harmonized standards. Its value should exceed 8.6 g/cm³ according to ASTM C 62 / 2013 [24]. Because of the decomposition of calcite present in relatively appreciable amounts in clay, the compressive strength of waste free bricks fired to 800 °C is lower than that of samples fired at lower temperatures although still above the minimum prerequisite (Fig 9).

As waste is added, a remarkable difference can be spotted between samples fired at 800 °C and those fired at lower temperatures. For these latter samples, addition of waste steadily decreased the compressive strength owing to increased porosity. Samples containing up to 25% waste fulfilled the minimum prerequisite value of 8.4 MPa. On the other hand, samples fired at 800 °C behaved in a totally different way. As can be seen from Fig (9), there was a spectacular rise in strength at low levels of waste addition followed by a gradual decrease in strength on increasing waste addition. The 34 MPa value recorded at 10% waste is in the same range of that of structural concrete. According to Greidmeyer et al [23], the presence of calcium sulfate crystals on the periphery of a black carbon core improves its compressive strength. According to the analysis of raw materials presented in Table (1), clay contains about 6.17% sulfate ions (calculated as $SO_3$) most of which will be in the calcium form as evidenced by XRD analysis (Fig 2a). The corresponding amount in waste is much less but will still be of some impact for low levels of waste addition. If however, more waste is blended with clay, the increased amount of waste added will contribute to the formation of larger black core clusters; in that case the limited amount of calcium sulfate present will fail to envelop all such clusters. The direct consequence will be a decrease in strength following higher levels of addition.

Fig (9): Effect of waste addition on compressive strength
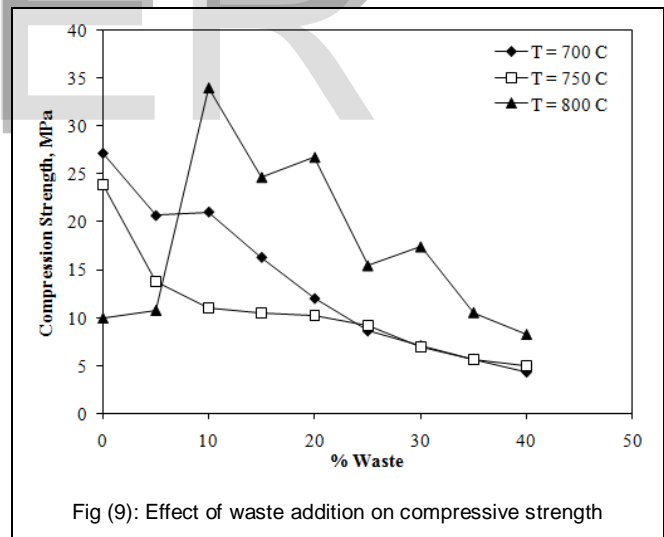
The presence of black core formed by incomplete combustion of organic impurities was observed in all samples. However, this was surrounded by a halo of white patches for samples containing 15% waste fired to 800 °C as can be observed in Fig (10). To assess the formation of calcium sulfate around the black core this region was subjected to EDAX analysis and the result shown in Fig (11) whereby it is clear that an elevated amount of calcium was detected in the subjected region.

## 3.4 Selection of Suitable Clay–Waste Mixture

Following the previous discussion, it was concluded that up to 10–15% waste could be added to desert clay without much affecting the plasticity of wet mixtures. It is recommended to fire the produced bricks to 700 °C so as to meet the main requirement of ASTM C 62 / 2013 [24] for compressive strength of normal duty NW bricks (min 8.6 MPa) and even that of MW type used under more severe conditions (min 15.2 MPa). There are no strict requirements for boiling water absorption although it should not exceed 25% for the MW type. From Fig (5) and (9), these conditions are fulfilled for bricks containing up to 15% waste fired at 700 °C. An additional advantage is the lower density of the produced bricks compared to plain ones. From Fig (8), it appears that bricks containing 15% waste have a bulk density of 1.59 g/cm$^3$ compared to 1.74 g/cm$^3$ for plain bricks, a decrease of about 9%. The economic merit of firing at that temperature coupled with the environmental benefit of reusing dumpsite waste both favor the use of that mixture.

It should be noted that although this research is of local nature, it can be implemented to suit other types of clays or domestic waste by following the same methodology adopted in this work.
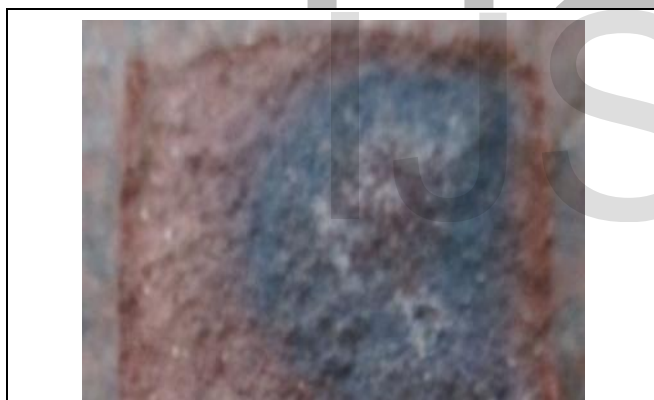


Fig (10): White patches around black core for sample containing 15% waste fired at 800°C
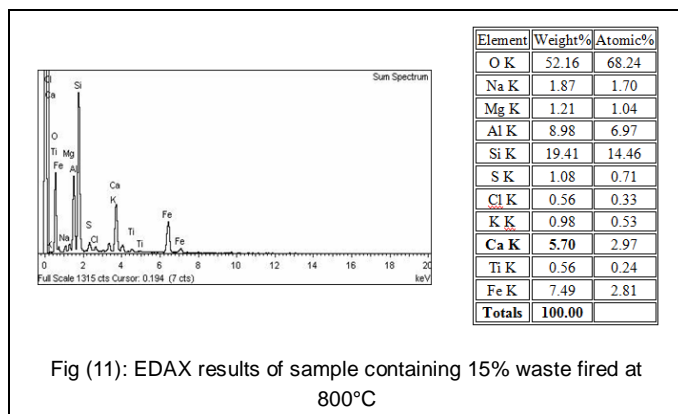


Fig (11): EDAX results of sample containing 15% waste fired at 800°C

## 4 CONCLUSIONS

This study is an attempt to use a landfill waste in the manufacture of clay bricks. The feasibility of using this waste at lower firing temperature than used industrially was demonstrated. The following conclusions could be drawn:

– An increase in waste content has for effect to slightly decrease plasticity of wet mixtures up to 15% addition. This was followed by a sharper reduction in plasticity on further addition of waste. The same trend was observed for linear drying shrinkage and green compressive strength.

– The values of water absorption are comparable on firing at 700 and 800 °C where as they are lowest at 750 °C, the addition of waste generally increasing water absorption. This was interpreted in light of decomposition of calcium carbonate present in raw materials. In the same way, increasing the level of waste addition lead to an increase in apparent porosity.

– For waste free samples, firing at 800 °C produced bricks with lower compressive strength than those fired at lower temperatures due to the formation of pores on calcination of calcium carbonate. On adding waste, there was a spectacular rise in strength at low levels of waste addition followed by a gradual decrease in strength on increasing waste addition reaching a value of strength comparable to that of plain concrete. This was interpreted in the light of formation of calcium sulfate surrounding the formed black core. In any case, the addition of waste up to 15% level and firing at 700 or 750 °C produced bricks that have strengths compatible with ASTM C 62 / 2013 standards for both NW and MW type bricks.

It was recommended to blend the used desert clay with dumpsite waste at 10 to 15% and firing to 700 °C which is much lower temperature than that used industrially (about 900 °C). The economic merit of firing at that temperature coupled with the environmental benefit of reusing dumpsite waste both favor the use of that mixture.

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