# Physical and Chemical Properties of Crushed Ceramic and Porcelain Clay Tile Powder

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## ABSTRACT

*This study focussed on establishing the physical and chemical properties of crushed ceramic and porcelain clay tiles for use as partial replacement of cement in production of eco-friendly concrete.Samples of ceramic and porcelain clay tiles were taken in accordance to BS 1881-101: 1983, which gives methods of sampling. Five kilograms of each material (ceramic and porcelain clay tiles) was picked from each of the five sampled sites within Kampala metropolitan area. The chemical composition of the ceramic and porcelain clay tile powder was determined using X-Ray Fluorescence Spectrometer method while the physical properties were determined using the ASTM C187 and ASTM C188. A comparison between the properties of the waste materials and cement was made to verify if its composition warrants it to be used as a pozzolan. The results show that the combined percentage of silica ($SiO_2$), Iron Oxide ($Fe_2O_3$), and Alumina ($Al_2O_3$) for both crushed ceramic and porcelain clay tile powder was meeting the 70% minimum requirement of ASTM C 618 for a good pozzolan.*

## Keywords

*Ceramic powder; porcelain powder; physical and chemical properties*

## 1. INTRODUCTION

Ceramic is defined as inorganic and non – metallic solids which can be highly crystalline, semi crystalline, vitrified or completely amorphous. Ceramics are grouped into two main groups which include the crystalline ceramics and the non-crystalline ceramics. The crystalline ceramics are found to be non-submissive to the wide range of processing and hence the crystalline ceramic is prepared in a desired shape either by reaction on site or by forming powders in the desired shape and then heating it until it becomes a solid mass. On the other hand, the non-crystalline ceramics are made from melts. The shape of the glass is formed either on a molten state or when it is in a toffee like viscosity(Sivaprakash et al., 2016).

Ceramic wastes can be separated in two categories in accordance with the source of raw materials. The first one are all fired wastes generated by the structural ceramic factories that use only red pastes to manufacture their products, such as brick, blocks and roof tiles. The second one is all fired waste produced in stoneware ceramic such as wall, floor tiles and sanitary ware. These producers use red and white pastes; nevertheless, the usage of white paste is more frequent and much higher in volume. (Pacheco et al., 2010).

Porcelain tile is a highly vitrified material produced from a body formulated by mixtures of kaolin, quartz and feldspar. The kaolin [$Al_2Si_2O_5$ $(OH)_4$], gives plasticity to the mixture; flint or quartz ($SiO_2$), maintains the shape of the formed article during sintering; and feldspar [$(K, Na)_2O$. $Al_2O_3$. $_6H_2O$], serves as flux. These three constituents place porcelain in the phase system [$(K, Na)_2O$-$Al_2O_3$- $SiO_2$)] in terms of oxide constituents, hence the term triaxial porcelain tiles (Buchanan, 1991 and Olupot, 2006). The main phase composition of a porcelain body is constituted by a heterogeneous glassy matrix and needle shaped mullite crystals together with some quartz grains and closed irregular shaped pores. Because of the complex interplay between raw materials, processing routes and the kinetics of the firing process, porcelains represent some of the most complicated ceramic systems (Lopez, 2011).

The differences between ceramic and porcelain tile lies in the fact that both are made with clay, but ceramic tiles also have sand mixed in. Porcelain tile tends to be made with denser clay than ceramic. Ceramic tile is a product that stands out for its low water absorption and high mechanical strength. The properties of the product result from its low porosity due to the processing conditions (high degree milling of raw materials, high force compaction and sintering temperature), and the potential of the raw materials to form liquid phases during sintering (high desiccation). Porcelain tile on the other hand is a type of ceramic material which has high vitreous characteristics. (Perez et al., 2013).This study, therefore, seeks to establish the physical and chemical properties of crushed ceramic and porcelain clay tiles obtained from demolished structures around Kampala metropolitan and its environs.

## 2. LITERATURE REVIEW

A number of researches have been carried out to find the properties of ceramic and porcelain tiles. Braganca et al. (2004) investigated the mechanical properties of porcelain. They reported the optimum sintering temperature for the porcelain studied was 1340$^{o}$ C using a heating rate of 150 C/h and a 30 min soaking time. The authors recorded the technical parameters are summarized such as water absorption: 0.34%, apparent porosity: 0.84%, bulk density: 2.48 g/cm$^{3}$ linear shrinkage: 12.2% modulus of rupture: 46 MPa. The authors added that the maximum strength is a result of decrease in porosity and internal flaws. Samples fired at temperatures below the ideal (1340$^{o}$ C) showed open porosity. On the microstructural analysis Braganca et al. (2004) revealed that the ideal firing temperature occurs when the glassy phase covers the entire sample surface with sufficient time to react with crystalline phases. Higher temperatures were limited by the porosity increase. This porosity is a result of oxygen released from $Fe_2O_3$ decomposition and gas expansion in the pores.

Stathis (2004) asserts that filler grain size has severe impact on the mechanical and physical properties of porcelain compared to the impact of the other three factors, namely quartz content in the filler, firing temperature and soaking time that were tested. Thus, optimization efforts should be focused on this factor. According to Stathis (2004), bending strength is affected by quartz grain size in two ways, directly through the induction of compressive stresses to the vitreous phase and indirectly through the development of a favourable microstructure. He stressed that both the parameters depend strongly on the particle distribution of quartz grains. He recorded the optimum quartz grain size is 5 – 20 μm which gives the maximum bending strength. However, he noticed that the use of coarser grain sizes results in reduced bending strength due to the development of a detrimental microstructure for the mechanical properties.

The chemical compositions of ceramic waste and porcelain tile powder has been established to vary greatly based on the type of ceramic tile. The main chemical components being $SiO_2$ which is found in the largest proportion followed by $Al_2O_3$. Other minor chemical constituents include $Fe_2O_3$, CaO, MgO, $Na_2O$, $K_2O$ while $TiO_2$ is the least found chemical constituent. The chemical composition of the ceramic waste will also tend to influence the specific gravity of the ceramic waste as established by Siddesha, (2011) who conducted a study using homogeneous ceramic tiles.

## 3. MATERIALS AND METHODS

The vast majority of tile found on demolition sites in the Uganda is made with either ceramic or porcelain. Figure 2 shows a sample of ceramic and porcelain tile waste at one of the demolition site in Bukoto.Samples of ceramic and porcelain clay tiles was taken in accordance to BS 1881-101: 1983, which gives methods of sampling. Five kilograms of each material (ceramic and porcelain clay tiles) was picked from each of the five sampled sites within Kampala metropolitan area. They were washed and left to air dry, crushed in the laboratory into powder.

**Figure 1: Ceramicclay tile waste at demolition site**

Figure 2describes the scientific experiments conducted using same basic elements albeit augmented by sophisticated tools and methods.

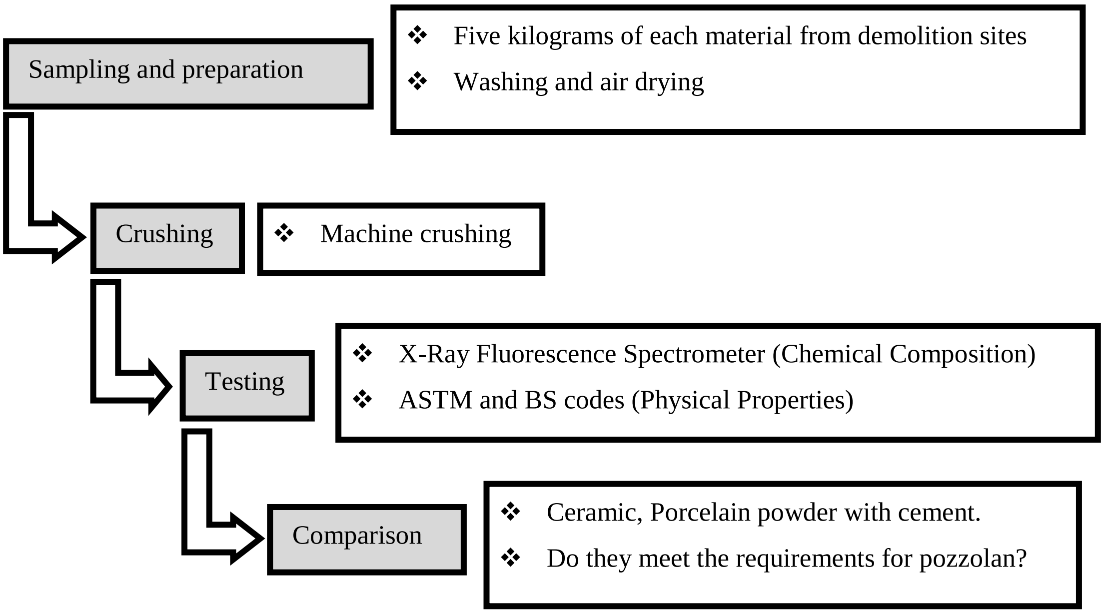


**Figure 2: Experimental setup**

The physical of crushed ceramic and porcelain clay tile was determined in accordance to the relevant standards. American Standard of Testing Materials (ASTM) and British Standard (BS) test methods were used to establish the physical and chemical properties of the crushed powder. X-Ray fluorescence Spectrometer method was used to determine the chemical composition of the crushed ceramic and porcelain clay tile powder. The test method used to establish each property is given in Table 1.

**Table 1: Test Methods for properties of crushed ceramic and porcelain clay tile powder**

| Property | Test Method |
|---|---|
| Specific Gravity | ASTM C 188 |
| Consistency | ASTM C 187 |
| Setting Time | BS EN 196-3:2016 |
| Chemical Composition | X-Ray Fluorescence Spectrometer |

From the test results, conclusions were made to justify whether crushed ceramic and porcelain clay tiles possess adequate pozzolanic properties to warrant its use as partial cement substitute in concrete production.

## 4. RESULTS AND DISCUSSION

**Table 1: Physical properties of Cement, Ceramic and Porcelain powder**

| Property | Ordinary Portland Cement | Ceramic Powder | Porcelain Powder |
|---|---|---|---|
| Specific Gravity | 3.15 | 2.95 | 3.11 |
| Consistency | 30 | 32.5 | 35.0 |
| Initial Setting Time | 30 minimum | 70 | 45 |
| Final Setting Time | 540 maximum | 475 | 320 |
| Colour | Grey | Reddish Brown | Grey |

**Table 2: Chemical Composition Ceramic and Porcelain powder**

| Major Components | Chemical Composition (% by mass) | | |
|---|---|---|---|
| | Ceramic powder | Porcelain powder | Ordinary Portland Cement Standard |
| $SiO_2$ | 66.39 | 73.04 | 21.03 |
| $CaO$ | 3.64 | 1.43 | 64.67 |
| $Al_2O_3$ | 18.14 | 19.39 | 6.16 |
| $Fe_2O_3$ | 3.79 | 1.42 | 2.58 |
| $MgO$ | 3.60 | 1.58 | 2.62 |
| $K_2O$ | 3.39 | 2.56 | 0.61 |

The major compounds of ordinary Portland cement are listed in Table 2. About 95% of portland cement clinker is made of combinations of four oxides. These are: lime (CaO), silica($SiO_2$), alumina ($Al_2O_3$), and iron oxide ($Fe_2O_3$). Other, so-called minor constituents or impurities include, among others, magnesia; sodium, and potassium oxides. Since the primary constituents of Portland cement are calcium silicates, one can define portland cement as a material that combines CaO and $SiO_2$ in such a proportion that the resulting calcium silicate will react with water at room temperature and normal pressure.

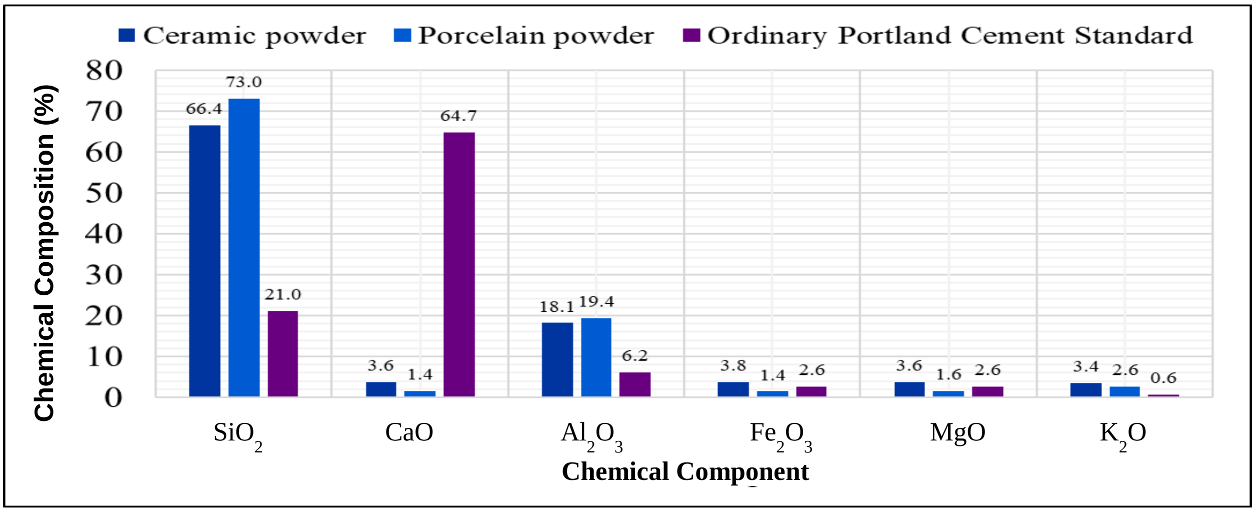


**Figure 3: Chemical composition of cement, ceramic and porcelain powders**

From Figure 3, it is clear that both ceramic and porcelain clay tile powder contain respectively 88.32% and 93.85% of$SiO_2$, $Fe_2O_3$ and $Al_2O_3$.

## 5. CONCLUSION

At the end of the study, the following conclusions are drawn:

(i) The physical properties of crushed ceramic and porcelain clay tile powder are closely related to those of ordinary portland cement.

(ii) From the Table 2, it can be seen that the combined percentage of silica ($SiO_2$), iron oxide ($Fe_2O_3$), and alumina ($Al_2O_3$) for both crushed ceramic and porcelain clay tile powder was meeting the 70% minimum requirement of ASTM C 618 for a good pozzolan.

## 6. RECOMMENDATIONS

From this experimental study the following recommendations were made for further research:

(i) For possible applications

- Crushed ceramic and porcelain clay tile powders may be used to replace cement partially or even at high proportions in in the production of eco-friendly concrete.

(ii) For further study:

- Other physical properties such as fineness, specific surface, water demand, soundness, and density among others may be further studied.
- Mechanical and thermal properties of ceramic and porcelain clay tile powders should also be investigated.

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