Waste Technology (WasTech)
Journal homepage: http://ejournal.undip.ac.id/index.php/wastech
An International Journal

Effect of Partial Replacement of Kaolin with Waste Sanitary Ware in the Production of Ceramic Socket

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Abstract - *The research investigates the utilization of waste materials from recycled sanitary ware in the manufacture of ceramic sockets. The debris is often thrown away in surroundings of building and land fills. However, they can be recycled to provide sustainable solution to the melting problems on wall plugs. In order to create the right ceramic materials for the research, raw materials like kaolin, ball clay, and feldspar are extracted from old ceramic sinks, toilets, and bathtubs. The research's goal is to use processed ceramic materials to address the melting problem with wall sockets. Additionally, it uses an experimental procedure to create ceramic sockets from waste sanitary ware and other materials. The materials are processed, mixed, pressed, dried, and fired to achieved the desirable result. Sanitary ware waste was used to replace kaolin at intervals of 5% variation. According to the outcomes of the tests, adding recycled sanitary waste to ceramic sockets enhances their physical, mechanical, and dielectric strength. The addition of sanitary ware waste has increased the dielectric strength property, compressive strength results as also shown the strength of sanitary ware wastes compare to that of kaolin. The findings have shed light on the viability and possibility of employing recycled sanitary ware waste products in the manufacture of ceramic sockets. It also meets up to the British Standard for plug and socket BS 1363, which has the ability to withstand high and low temperature for both residential uses 120-240v and industrial usages. The sample produced pass the least dieletric strength for any insulator at 3kΩ/mm resulting into a mega ohm (mΩ).*

Keywords *– Sanitary ware, Clay material, Insulator, Ceramic Socket, Kaolin Replacement*
Doi: http://dx.doi.org/10.14710/wastech.12.1.20-27
[How to cite this article: Peter, O. T., Hossanah, C. (2024). Effect of Partial Replacement of Kaolin with Waste Sanitary Ware in the Production of Ceramic Socket. Waste Technology, 12(1), 20-27 doi: http://dx.doi.org/10.14710/wastech.12.1.20-27]

1. Introduction

The production of ceramics has been an integral part of human civilization for thousands of years, serving various purposes in our daily lives [2]. Ceramic sockets, in particular, play a crucial role in electrical installations, providing a safe and efficient connection for electrical devices. Traditionally, the main raw material used in ceramic production is kaolin, a type of clay known for its favorable properties such as plasticity and high temperature resistance [2]. However, with growing concerns over environmental sustainability and waste management, exploring alternative materials for ceramic production has become a significant area of research.

According to [1] one such alternative material that has gained attention is waste sanitary ware, which refers to discarded or broken bathroom fixtures like toilets, sinks, and bidets. These sanitary ware items are typically composed of ceramic materials similar to those used in socket production, making them a potential materials for partial replacement of kaolin. The utilization of waste sanitary ware as a substitute for kaolin offers several benefits, including waste reduction, conservation of natural resources, and cost-effectiveness.

The aim of this paper is to investigate the effect of partial replacement of kaolin with waste sanitary ware in the production of ceramic sockets. By analyzing the physical, mechanical, and electrical properties of the resulting ceramic sockets, we can evaluate the feasibility and viability of using waste sanitary ware as a sustainable alternative raw material to kaolin in ceramic socket production.

The partial replacement of kaolin with waste sanitary ware introduces a new dimension to ceramic socket production, potentially influencing various aspects such as material composition, manufacturing processes, and final product performance. Some key factors that were considered in this study include the percentage of waste sanitary ware to be used, the processing conditions, and the resulting properties of the sockets.

[5] agreed with [1] stating the perfect replacement of sanitary waste to kaolin in ceramic socket production would not only address the environmental challenges associated with waste management but also contributes to the development of sustainable manufacturing practices within the ceramic industry. The findings in this study paved the way for a more sustainable approach to ceramic production,

reducing the reliance on virgin raw materials while promoting the circular economy.

2. Literature Review

Ceramic production is a significant industry that relies heavily on the use of raw materials such as kaolin for the manufacturing of various products, including ceramic sockets. However, the extraction and utilization of kaolin have raised environmental concerns and highlighted the need for sustainable alternatives. One promising solution is the partial replacement of kaolin with waste sanitary ware in ceramic socket production. This literature review aims to explore the effects of this innovative approach on the properties and sustainability of ceramic sockets.

2.1. Kaolin in Ceramic Production

Kaolin, a naturally occurring clay mineral, is traditionally used as a key component in ceramic production due to its excellent plasticity and ability to enhance the properties of ceramic products. It provides desirable characteristics such as whiteness, high-temperature resistance, and strength, making it a valuable material for socket manufacturing [6]. The kaolin used for this study was varied with sanitary ware waste in order to reduces the excessive use of kaolin.

2.2. Waste Sanitary Ware as a Replacement Material

Waste sanitary ware, which includes discarded bathroom fixtures and ceramics, offers a sustainable alternative to kaolin. It possesses inherent characteristics, such as fired and vitrified properties, which make it suitable for use in ceramics [2]. The recycling of waste sanitary ware reduces the environmental impact associated with the disposal of such materials and contributes to the circular economy. Sanitary ware waste that was used in this study helps to improve the mullite phase of the ceramics socket.

2.3. Effects on Ceramic Socket Properties

Numerous studies have investigated the impact of replacing kaolin with waste sanitary ware on the properties of ceramic sockets. Findings indicate that the partial replacement can lead to changes in mechanical, thermal, and aesthetic properties. For instance, the addition of waste sanitary ware had affected the socket's compressive strength, thermal conductivity, and surface finish from the result gotten.

2.4. Processing and Manufacturing Considerations

The utilization of waste sanitary ware in ceramic socket production requires adjustments in processing and manufacturing methods. Researchers have explored various techniques to incorporate waste sanitary ware effectively. These methods include optimizing firing conditions and material composition to achieve the desired properties while minimizing production challenges [11].

2.5. Environmental and Economic Impacts

One of the most significant advantages of using waste sanitary ware as a partial replacement for kaolin is its positive environmental impact. By diverting waste materials from landfills and reducing the demand for raw materials, this approach contributes to environmental sustainability [2]. Moreover, it has the potential to lower production costs, offering economic benefits for manufacturers.

2.6. Case Studies and Experimental Findings

Several case studies and experiments have been conducted to assess the feasibility and efficacy of using waste sanitary ware in ceramic socket production. These studies provide valuable insights using past tables into the practical application of this approach and its impact on product quality and performance

Table 1. Past Composition of Some Authors on porcelain composition

Authors	Quartz %	Kaolin %	Ball clay %	Feldspar %
Manzuche (1991)	12	32	8	48
Anih, I.A (2005)	38	30	10	22
Kashim, I.B (2004)	25	50	-	25
Kamseu, E et al, (2006)	25	-	50	25
Rajamannan, B et al (2007)	25	30	30	15
Joseph, C et al, (2007)	20	18	32	30
Olupot, (2006)	25	30	15	30
Oladiji et.al. (2010)	20	33	15	32
Okolo et. al. (2015)	20	-	50	30
Singer and Singer (1963)	25	50	-	25

Source: [15]

This study adopted [16] composition making other materials constant except kaolin which was varied at interval with sanitary ware waste. [13] Kaolin contain high mullite property and had been used to poduced sanitary ware waste.

3. Materials and Method

Material: Quartz, ball clay, kaolin, feldspar, and waste from sanitary ware are the materials used in this inquiry. Feldspar, quartz, and kaolin were obtained from Auchi, Edo state Nigeria, while sanitary ware waste was gotten from renovation site within the campus at the Federal University of Technology, Akure.

Methods: The excavation of the study area's raw materials resulted in their packing, bagging, and transportation to the laboratory for experimental analysis.

To reduce the amount of moisture in the ball clay material and make the pounding and grinding of the materials easier, the material was first sun-dried for two weeks. After using a mortar and pestle to break up any lumps, the dry samples were further ground into extremely small particles by utilizing a grinding machine. The materials for sanitary ware were first broken into smaller pieces to make them easier to pulverize, and they were then sieved through a 150-micron mesh after pulverization. All the ingredients were weighed out and added to the balling mill when it was dry to start reducing the particle size. The homogeneous mixture was then used to create the test sample.

The materials were thoroughly mixed together with water and were molded into a wooden cubic mold of 50 × 50 × 50mm in accordance with the standard precision of an Automatic Digital Readable machine (ADR). Using [16] composition, kaolin was varied with sanitary ware waste and five replicates of each sample composition were also made in order to have enough samples for the tests that were carried out. The samples produced were sundried for some weeks to remove moisture from it before it was fired in an electric kiln to 1150ºc.

Table 2. Olupot Composition

Kaolin	Ball Clay	Feldspar	Quartz
30	15	30	25

Source: Olupot (2006)

Table 3. Body Composition of Sample Test

Samples	Sanitary ware waste (S.W.W)	Kaolin	Feldspar	Ball clay	Quartz
A	5	25	30	15	25
B	10	20	30	15	25
C	15	15	30	15	25
D	20	10	30	15	25
E	25	5	30	15	25

Tests Procedure: The following tests were carried out on the samples produced to ascertain the suitability of the materials and compositions for ceramic socket production; the procedures are as well explained:

Water Absorption: The percentage of the relationship between the weight of the water absorbed to the weight of the dry samples was determined using the below formula:

$$\text{Water absorption (A\%)} = \frac{W-D}{D} \times \frac{100}{1} \qquad \text{Equation (1)}$$

Where,

W = weight of the water absorbed specimen

D = weight of the Dry specimen.

Using [3], the test samples were boiled for two hours, submerged into water for 14 hours right after being removed from the pot, the weight of the sample was measured using a beam balance immediately after it was removed from the water. The weight of the dried test samples was divided by the weight of the soaking test samples, and the difference was multiplied by 100 to get the final result from equation (1).

3.1. Mechanical Analysis:

The mechanical analysis test was conducted at the Department of Civil Engineering, School of Engineering and Engineering Technology, Federal University of Technology, Akure Ondo State. Mechanical characteristics of the samples generated were examined using an Automatic Digital Readout Machine (ADRM), this was to identify the peak load at which the sample failed. Samples were placed into the machine one at a time and subjected to the force of the (ADR), the force exerted and the samples' cross-sectional area were used to calculate the sample's compressive strength using the below formular in equation (2).

$$\text{Compressive Strength} = \frac{Force\ Applied\ (N)}{Cros-Sectional\ Area\ (mm)} \qquad \text{Equation (2)}$$

3.2. Electrical Analysis.

The dielectric property test was conducted on the samples produced at the National Electrical Management and service Agency (Akure Area) under the Ministry of Power and Mines, Federal Secretariat, Igbatoro Road, Akure. The electric property of the samples produced was done in two ways to determine the:

i resistivity of the samples; and

ii dielectric strength of each sample.

These were done using a meggar tronic. The meggar tronic has two terminal points with the cathode and anode, the cathode and anode was placed on two ends of the copper wire that was tied around the sample so as to determine their resistivity and strength of each sample.

Two different samples in each were tested using the meggar tronic so as to determine an accurate result and to avoid error due to parallax. Each sample was placed on both 500 MΩ and 1000 MΩ to determine their strength and resistivity. Record of each sample tested was taken within 30 seconds.

4. Result and Discussion

4.1. Analyze the Phase Chemical Composition of the collected Raw Material using X-ray Fluorescence;

Sanitary ware waste (S.W.W), kaloin, ball clay, quartz, and feldspar were among the sample materials that were submitted to the Engineering Material Development Institute (EMDI) in order to determine their basic constitutes.

4.1.1. Chemical Composition of Ball Clay from Ishan Ekiti

Fig 1 indicates 30% of Iron oxide (Fe_2O_3), 45% of silica (SiO_2), and 24% of alumina (Al_2O_3) was highly present in the ball clay as a result of the material. Silica, which had the largest quantity, helps the materials in hardness and strength, while iron oxide enables the samples to be plastic in nature. Alumina, which is present in the materials, helps them become more plastic and it also boosts the bonding strength of the materials. The outcome was consistent with the theory put forward by [12] according to which a high impurity (Fe_2O_3) content causes a reddish colouration after firing.

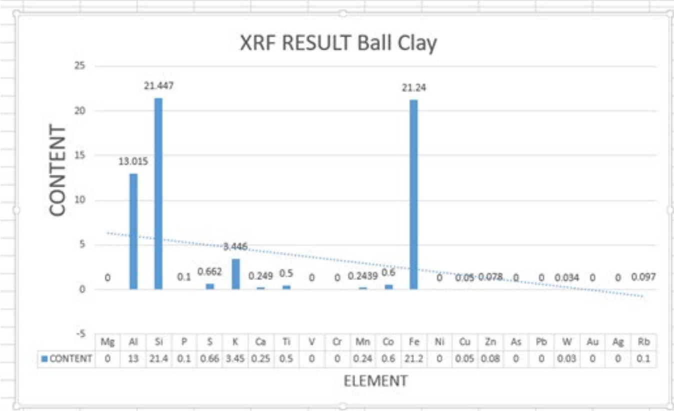

Figure 1. XRF for Ball Clay

4.1.2. Chemical Composition of Feldspar from Auchi

Fig 2, this study was found to be in agreement with [7]. The results of the X-ray fluorescence test show high percentages of silica (SiO_2) at 23%, alumina (Al_2O_3) at 49%, and potassium oxide 19% (K_2O), which are shown in Fig 2 in decreasing order. The presence of flux (K_2O. Al_2O_3.6SiO_2) caused the outcome to reduce in it melting temperature. The feldspar utilized in this investigation had the chemical formula (K_2O. Al_2O_3.6SiO_2) and was a potash feldspar.

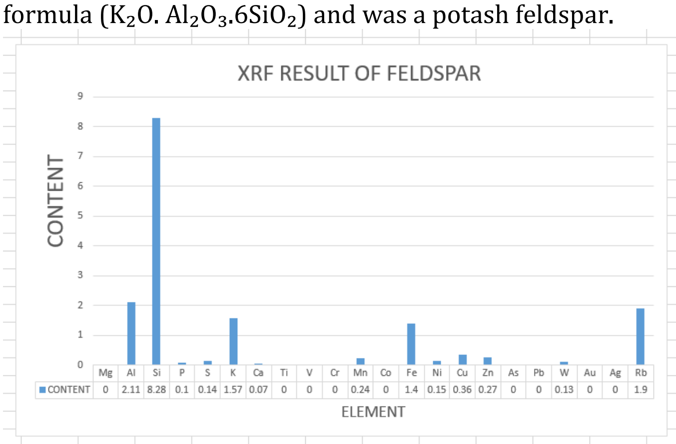

Figure 2. XRF for Feldspar

4.1.3. Chemical Composition of Kaolin from Auchi

The X-ray fluorescence result from fig 3 supported [9] findings, which says kaolin has the highest concentration of silica and alumina. It also demonstrates the presence of potassium and iron oxide in the composition. The presence of alumina aids in strength and thermal stability, while the silica aids in shrinkage and firing behavior. Iron oxide also contributed to the sample's reddish colour. Additionally, it was discovered that the kaolin has impurities.

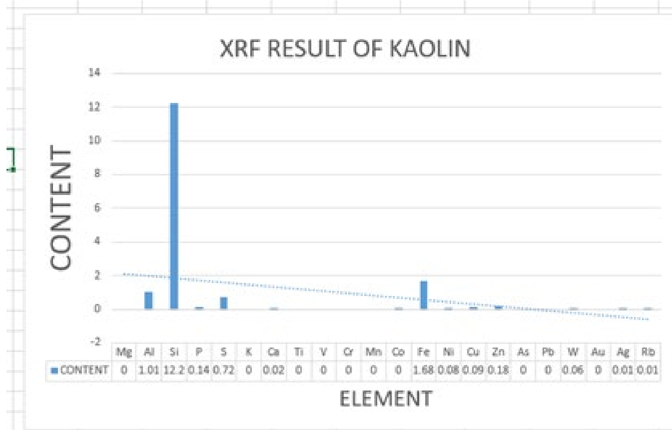

Figure 3. XRF for Kaolin

4.1.4. Chemical Composition of Quartz from Auchi Observation

SiO_2 was more prevalent than other elements, as indicated in Fig. 4, and the quartz utilized in this study has less iron oxide Fe_2O_3, which is a sign of impurity. Additionally, it resists thermal shock, enhances the samples' thermal stability, and helps them tolerate high temperatures between 500 and 1000 (MΩ). The X-ray fluorescence result supported the findings of [12] that iron oxide (Fe_2O_3), lithium oxide, sodium oxide, or potassium oxide (K_2O) impurities can be found in quartz (SiO_2).

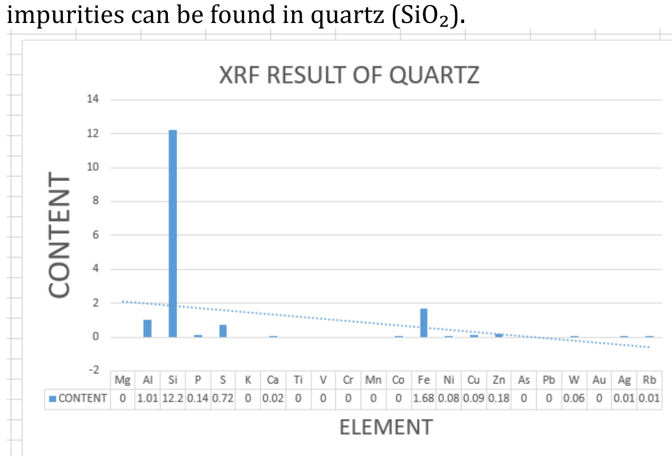

Figure 4. XRF for Quartz

4.1.5. Chemical Composition of Sanitary ware wastes Observation

The X-ray Fluorescence results from Fig 5 shown, silica has the largest percentage of 35%, followed by alumina 15% and potash feldspar 8%. The present of iron oxide 25% is a sign of impurity and was revealed to have a higher content than alumina and potash. This agreed with [18] stated that every sanitary ware has the largest percentage of silica and more impurity.

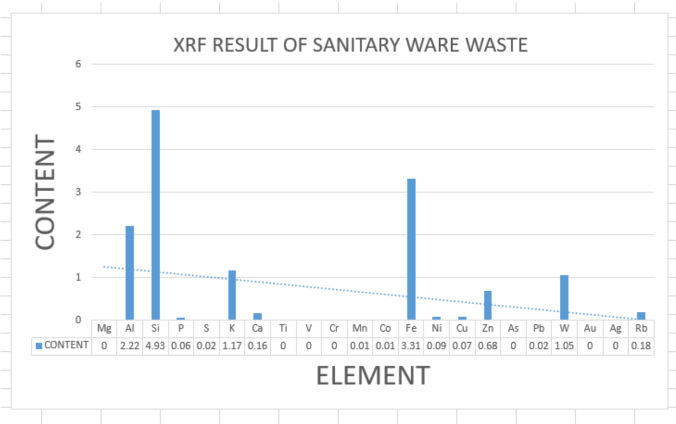

Figure 5. XRF for Sanitary ware wastes

4.2. Vary Kaolin Composition (%) to Sanitary ware waste to determine its suitability for Ceramic Sockets Production

Each combination produced a different colour, with sample A being lighter than sample B. As with the other samples, the colour changes more as sanitary ware waste was added to it. A total of 6 samples were created, and each sample received 5 replications for a grand total of 30 samples. The samples used in the test had varying strengths, insulating properties, and physical characteristics

Figure 6. Fired Samples

4.3. Determine the Functionality, Physical, Strength, and Dielectric strength

4.3.1. Dielectric Strength

This is the breakdown voltage at which the body of each sample cannot resist the current that passes through the materials. Each sample was tested at 500MΩ using an Insulation Tester at the National Electrical Management and Service Agency (Akure Area), Ministry of Power and Mines, Federal Secretariat, Igbatoro, Akure, Ondo State.

The result from each sample was tested at 500MΩ to determine its suitability. Sample A has 581 MΩ, sample B had 377.5 MΩ, sample C had 218, sample D as 679.5, sample E as 598 and sample F as 630 at 500MΩ. The result shows that sample D had the highest insulating properties at 500MΩ. The inclusion of sanitary ware waste has helped in increasing the dielectric strength of the samples. The more sanitary ware waste is re-fired at high temperature the more the insulating properties increases.

Table 4. Dielectric Strength

SAMPLE	500MΩ
A	581
B	377.5
C	218
D	679.5
E	598
F	630

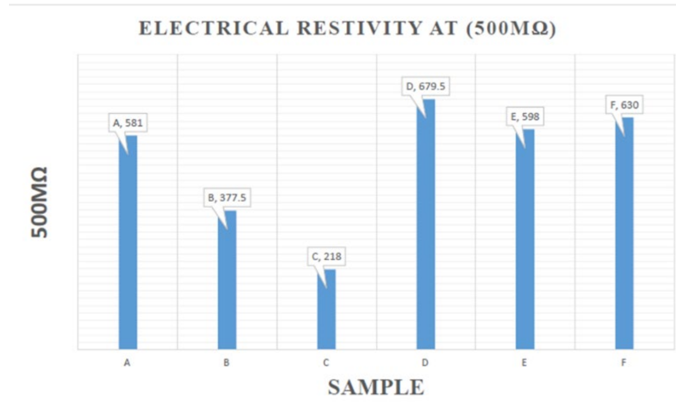

Figure 7. Electrical Resistivity at 500 MΩ

Observation

Figure 7, graph displays the results of a dielectric strength test at 500 MΩ. Samples A to C showed a downward trend and contained more kaolin than sanitary ware waste, while samples D to F contained more sanitary ware waste and showed a better upward trend. The graph showed that sample D had the highest dielectric test result of 679.5 MΩ while sample C had the lowest dielectric test result of 218 MΩ. The strength of the insulating increases with the amount of sanitary ware waste present in the composition. The British standard for plug and socket BS1363 [4] shown that socket must have the ability to withstand low voltage at 120 -240v, [15] quoted [17] that the least dieletric strength for an insulator is 3kΩ/mm. All the sample produced resulted to mega ohm with have the ability to withstand both low and high voltage from table 4.

4.3.2. Compressive Strength Test

The Department of Civil Engineering of the Federal University of Technology, Akure, conducted the compressive strength test. employing an apparatus known as an Automatic Digital Readout Machine. The apparatus was used to gather the findings of this compressive strength test.

Table 5: Compressive Strength Test

SAMPLE	MPA
A	9.75
B	11.5
C	10.45
D	15.35
E	14.4
F	19.75

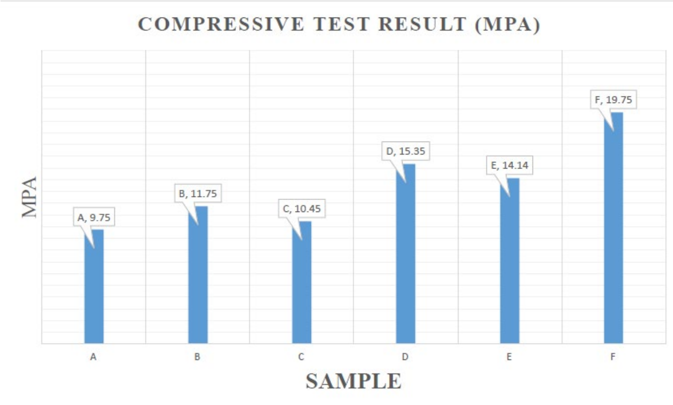

Figure 8. Compressive Strength Graph

Observation

The best mechanical and dielectric properties, according to [14], can be attained by increasing the amount of mullite and quartz, while reducing the amount of glassy phase and the presence of microcracks. [10] state that the minimum compressive strength on any insulating material is 3.0 MPa, all samples was successful passing the minimum compressive materials meanwhile sample F had the highest compressive result with 19.75 MPa. The increase in the amount of re-used sanitary ware waste has helped samples D and F achieve higher strength results than samples A and C, which had more kaolin.

4.3.3. Water Absorption

According to [3] the rate of absorption will increase as the rate of water consumption increases. Samples E and F had 13.89% and 12.46% respectively, sample A had 12.7%, sample B had 11.37%, sample C had 12.99%, sample D had 14.14%, and sample E had 13.99%.

Figure 9 show the trend of the water absorption rate of each sample in percentage, Sample A to C had a low rate of absorption compared to sample D to F which had high rate of absorption. Sample D had the highest trend with 14% while sample B had the lowest trend with 11.37% this agreed with [9].

Table 6. Water Absorption

SAMPLE	WEIGHT IN WATER (Gram)	WEIGHT IN PERCENTAGE (%)
A	271.9	12.7
B	266.8	11.37
C	268.7	12.99
D	256.65	14.14
E	266.35	13.89
F	252.25	12.46

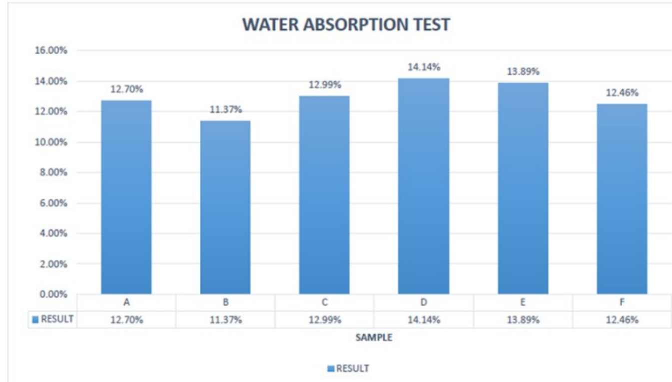

Figure 9. Water Absorption Test

4.4. Make Ceramic Socket Models using Computer-Aided Design (CAD) for Reproduction

The ceramic socket model was done using a Computer-Aided Design called Cinema 4D. The real size for a socket is 8.5cm by 8.5 cm, and the shrinkage result was added to 8.5cm square which makes it 9cm. The hole cut of each socket was calculated and another screw hole was observed during design.

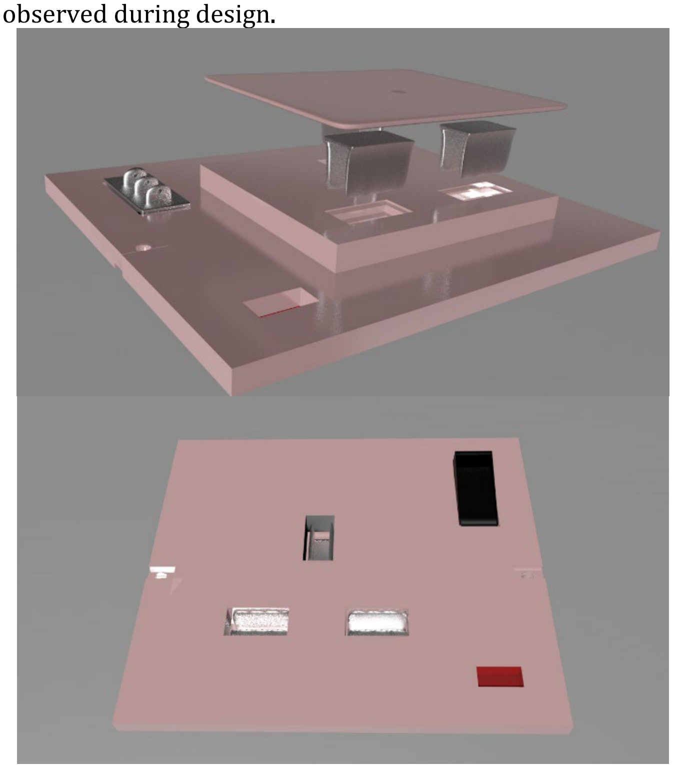

Figure 10. Computer Aided Design (Socket).

Figure 11. Dried Samples of the Socket

Figure 12. Fired Samples of the Socket

4.5. Glaze

The ceramics sockets that were fired were thoroughly coated in an ash glaze that was produced by [8], the temperature achieved using an electric kiln in an oxidized state was 1150°C. Before discharging items (sockets), the kiln was given three days to cool. Due of its placement in the kiln, the glaze came out in two distinct colour: deep brown and brownish.

Figure 13. Glazed Ceramic Sockets

4.6. Fixing of Ceramic Socket

The ceramic socket was fixed by joining the wire to its positive and negative parts, with the live linked to the switch and the neutral to the copper element, respectively. This was connected using a screw and screwdriver, and the quantity of electricity flowing into the ceramic socket was measured using a meter.

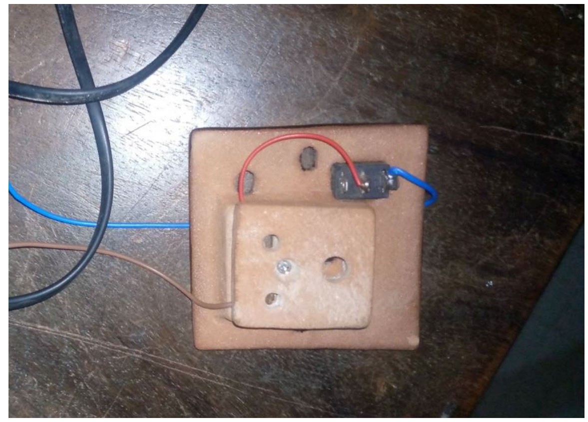

Figure 14. Fixed Ceramic Socket

5. Conclusion

The results of this study have demonstrated that the re-use of sanitary ware waste products can vary with kaolin or used without kaolin in sample F. This study also demonstrates that sanitary ware waste can resolve the melting problem in a plastic socket based on the results of the stated test that was conducted.

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