INFLUENCE OF ALUMINA AND SILICA RATIO ON GLOSSY SURFACE CHARACTERISTIC OF CERAMIC BODY FOR CERAMIC PRODUCTION

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ABSTRACT

This report shows the effect of alumina and silica ratio on the formation of glossy ceramic body that can be used for the forming of ceramic products. From the objectives of the experimental study, it was concluded that the ratio between Alumina and Silica at 1:10 and with the appropriate oxide content of both alkaline and alkaline earth groups helped to obtain a glossy ceramic body that could be used in the manufacture of ceramic products at a temperature of 1,200°C. The experiment started with the use of triaxial body compositions: containing clay, feldspar, and quart to test preliminary melting, then selecting to adjust the ratio between Alumina and Silica as well as oxide group of Alkali for the second stage test. Consider water absorption after firing, color, surface melting, analysis of Scanning electron microscope (SEM), and Energy Dispersive X-ray Spectroscopy (EDS/EDX).

Keywords: Glossy ceramic body, Ceramics products, Alumina and silica ratio

I. INTRODUCTION

“Ceramic” or “Pottery” is a product that is in close contact with all human beings in their daily lives, whether tableware, cooking ware, brick, tile, sanitary ware, and accessories, etc. Therefore, there is a preliminary understanding that “pottery” is a product made from clay, not glazing such as red brick, terracotta ware etc. “Ceramic” is products made from clay and glazing, such as tableware, cooking ware, and sanitary ware.

In the ceramics work, the key factor is the raw materials used for forming the product including ceramic body. It can be made from a single raw material such as red clay, ball clay, etc., or it can be from a composition of more than five raw materials to achieve the desired properties, such as white body, translucent body, high or low temperature sintering, resistant to sudden temperature changes (thermal shock resistance), etc. It is also necessary to use the same material to prepare the glaze suitable for the developed ceramic body. Therefore, there are many types of raw materials used in ceramic work, different properties, can be selected according to work. Ceramic body and glaze are obtained from the mixture ratio of clay, stone, and oxide. They differ in the ratio of ingredients to obtain different properties. Ceramic body need properties to form the desired product shape, glazes require properties for beauty in both color and gloss.

The creation of body compositions from three materials: Clay, Feldspar, and Quartz, also known as “triaxial body’s compositions”, has a wide range of uses (as in Reference No. [1]-[8]). Because it is a natural raw material that is inexpensive, readily available, and has good properties [9, 10]. The application of these three raw materials to create ceramic body for forming ceramic product, it has a glossy finish without glaze, and is burned only once. There will be opportunities in terms of both financial and time costs. An important problem of this experimental study was the evaluation of the ratio of Alumina and Silica on the formation of glossy ceramic body for use in the manufacture of ceramic products. The results of this study provide an important guideline to examine the influence of the molar ratios of Al\textsubscript{2}O\textsubscript{3} and SiO\textsubscript{2}, as well as alkali oxides: alkali metal oxides (R\textsubscript{2}O) and alkaline earth metal oxides (RO), affecting ceramic body for the production of ceramic products without glaze.

The main objectives were (1) to examine the properties of the ingredients of the three basic raw materials, namely Ball Clay, Potassium Feldspar, and Quartz, by using Tri Axial Diagram after calcination at 1,200°C. (2) To create a percentage mixture ratio of raw materials from the basic test results with the ratio between Al\textsubscript{2}O\textsubscript{3}:SiO\textsubscript{2} equal to 1:10, and has a high percentage of melting by adding raw materials that help melting (fluxing agent). (3) to test the influence of the ratio of Al\textsubscript{2}O\textsubscript{3}:SiO\textsubscript{2}, as well as RO and R\textsubscript{2}O on the characteristics of the glossy ceramic body; and (4) to compare the particle level characteristics of the...
experimental body with Cone No.5 by Scanning electron microscope (SEM) and Energy Dispersive X-ray Spectroscopy (EDS/EDX).

Literature data and new experimental results can be used to compare the physical and chemical properties of other glossy ceramic body: Cone, Soft Porcelain, and Bone China Bodies.

II. PROCESS DESCRIPTION

The mixture ratio of ceramic body was created using an Tri Axial Diagram. The experimental formula was 36 mixture ratios by using 3 main raw materials: Clay, Feldspar, and Quartz. It was a popular research design. Adjusting the toughness properties can add a material that improves machinability, such as Bentonite and a small amount of organic binder, to enable machinability. Or when the ratio is close to the demand, consider adjusting the mix ratio and considering the chemical composition of the raw materials together with the firing temperature, and the time of firing. In addition, the grain size of raw materials and ceramic body affects the desired surface condition, including grinding and forming methods [11].

For this study, 3 main raw materials, namely Ball Clay, Feldspar, and Quartz, were used to achieve the considered mixture ratio close to the desired property of glossy surface, able to form, and stabilize at a specified temperature. Using Ball Clay instead of raw materials that increase the toughness. Because the desired ceramic body does not determine the whiteness, which Ball Clay will have finer particles than Kaolin, but there are impurities that make the white more dull, including Ferric Oxide and Titanium Dioxide. Including adding raw materials that reduce the firing temperature (Flux) as raw materials that provide oxides in the alkaline group (Alkaline, Alkaline Earth) such as Whiting, Dolomite, Borax, Colemanite, and Soda Ash to make the ceramic body melt and form the surface shiny as desired. Considering the use of additional raw materials at an appropriate mix ratio.

Ceramic clay with a glossy surface. It is caused by the melting of the raw material during firing due to a number of factors [12-14], one of which is the chemical composition of the mixture ratio [15-18]. One factor affecting the luster of the product surface is surface smoothness caused by the fusion of raw materials [19]. However, a type of ceramic body that looks like a glaze after burning it. It has melted and softened at the point of maturity, including Cone. Therefore, it can be said that ceramic body with physical characteristics is body for forming, toughness, and stable without melting and deforming after firing at the specified temperature. But considering the chemical composition, cone may be classified as a group of glazes. As for the current ceramic body, the chemical composition and raw materials used cannot be distinguished from the glaze. It is classified by considering the nature of the change in condition during use. If it is a ceramic body for forming, it reacts when heated and forms a solid-solid or solid-liquid. But for the glazing, there is a whole process from preparation, use, and heat treatment in liquid phase only (complete liquid phase reaction) [11].

Found that the first cone inventor, Seger, H. created a mixture of Seger Cone with a ratio of $\text{Al}_2\text{O}_3:\text{SiO}_2$ equal to 1:10, that is, 0.6 mole of $\text{Al}_2\text{O}_3$ and 6 mole of $\text{SiO}_2$. For cone applications at 1200°C, increasing and decreasing the molar number of 0.1 mole $\text{Al}_2\text{O}_3$ and 1 mole $\text{SiO}_2$ can increase or decrease the cone number by one degree with a temperature difference of approximately 25°C together with the substitution of the molar number of $\text{K}_2\text{O}$ with other alkaline oxides. The operating temperature of the cone is not fixed to the required accuracy. If the slow or fast firing temperature is increased, accelerated sintering in a slow furnace causes the cone to fall at a lower temperature than accelerated sintering. For example, using a large Orton pyrometric cone No., if burned at a temperature of 60°C per hour, the cone will fall at 1,177 °C. If the temperature is increased to 150 degrees Celsius per hour, the cone will fall at 1,196 degrees Celsius [20].

In this study, the ceramic body was created at 1,200°C, using Orton Cone No.5 (1,196°C), which is comparable to Seger cone No.6a with an $\text{Al}_2\text{O}_3:\text{SiO}_2$ ratio of 1:10, i.e. 0.7 mole of $\text{Al}_2\text{O}_3$ and 7 mole of $\text{SiO}_2$, according to the above theory, it was found that Seger Cone No.6a for firing at 1,200°C has the empire formula as follows [21].

$$0.288 \text{ K}_2\text{O} \quad 0.693 \text{ Al}_2\text{O}_3 \quad 6.801 \text{ SiO}_2$$
$$0.013 \text{ Na}_2\text{O} \quad 0.020 \text{ B}_2\text{O}_3$$
$$0.685 \text{ CaO}$$
$$0.014 \text{ MgO}$$

III. MATERIAL AND METHOD

[www.turkjphysiotherrehabil.org](http://www.turkjphysiotherrehabil.org)
Experiment with ingredients by preparing 3 types of raw materials, namely Ball Clay, Potassium Feldspar and Quartz, by using Tri Axial Diagram (Figure 1), forming a powder body by pressing dry into a cone mold, and calcined at 1,200°C (Cone No.6), Oxidation Firing atmosphere, electric furnace, consider the properties after firing, as color and sintering.

After the first stage of testing, consider choosing a mixture ratio with a ratio of Al₂O₃:SiO₂ equal to 1:10, a high melting percentage. This experiment was used to create the percentage of mixture ratio of raw materials added to the fluxing agent, fired at 1,200°C, Oxidation firing atmosphere, electric furnace. Consider the characteristics after firing, including absorption, color, and sintering, and then select the best mix ratio for surface characterization at the particle level by Scanning electron microscope (SEM), and Energy Dispersive X-ray Spectroscopy (EDS/EDX) compared to Cone No.5.

The formula used for the calculation is as follows.

\[
\% \text{Sintering} = \frac{\text{Height before firing} - \text{Height after firing}}{\text{Height before firing}} \times 100 \quad (1)
\]

\[
\% \text{Water Absorption} = \frac{\text{Weight after boiling} - \text{Weight before boiling}}{\text{Weight before boiling}} \times 100 \quad (2)
\]

**IV. EXPERIMENTAL RESULTS AND DISCUSSION**

The ratios between Ball Clay, Feldspar, and Quartz of 36 mixture ratios were from Tri Axial Diagram after firing at 1,200°C, Oxidation Firing, electric furnace. It was found that the body texture was white-grey-cream (Figure 2). The raw materials are sintering with a percentage of smelting between 14.69-33.5% (Figure 3).
Figure 2. The results of the first stage experiment after firing at 1,200°C
When considering the ratio between $\text{Al}_2\text{O}_3$:SiO$_2$ equal to 1 : 10 (Figure 4), the body has a high melting percentage (26.9%), choose the mix no.26, consisting of 20% Ball Clay, 30% Potassium Feldspar, and 50% Quartz. Improve the percentage of ingredients of raw materials by adding raw materials that help melting (Fluxing Agent) shown in Table 1 and Table 2.

**Table 1. Percentage of raw materials for stage 2 experiments**

<table>
<thead>
<tr>
<th>No.</th>
<th>Ball Clay</th>
<th>Feldspar</th>
<th>Quartz</th>
<th>Whiting</th>
<th>Dolomite</th>
<th>Borax</th>
<th>Colemanite</th>
<th>Soda Ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1-1</td>
<td>20</td>
<td>30</td>
<td>50</td>
<td>12</td>
<td>0.5</td>
<td>0.3</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>A1-2</td>
<td>25</td>
<td>28</td>
<td>47</td>
<td>12</td>
<td>0.5</td>
<td>0.5</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>A1-3</td>
<td>30</td>
<td>25</td>
<td>45</td>
<td>12</td>
<td>0.5</td>
<td>0.3</td>
<td>0.2</td>
<td></td>
</tr>
</tbody>
</table>

**Table 2. The number of moles of oxides of the mixture ratio of the stage 2 experiment**

<table>
<thead>
<tr>
<th>No.</th>
<th>CaO</th>
<th>MgO</th>
<th>Na$_2$O</th>
<th>K$_2$O</th>
<th>Al$_2$O$_3$</th>
<th>B$_2$O$_3$</th>
<th>SiO$_2$</th>
<th>Al$_2$O$_3$:SiO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1-1</td>
<td>0.677</td>
<td>0.015</td>
<td>0.015</td>
<td>0.294</td>
<td>0.716</td>
<td>0.021</td>
<td>7.143</td>
<td>10</td>
</tr>
<tr>
<td>A1-2</td>
<td>0.690</td>
<td>0.015</td>
<td>0.015</td>
<td>0.280</td>
<td>0.818</td>
<td>0.021</td>
<td>7.105</td>
<td>9</td>
</tr>
<tr>
<td>A1-3</td>
<td>0.712</td>
<td>0.015</td>
<td>0.015</td>
<td>0.257</td>
<td>0.924</td>
<td>0.022</td>
<td>7.170</td>
<td>8</td>
</tr>
</tbody>
</table>

**Figure 3. Percentage of melting**

**Figure 4. Ratio of $\text{Al}_2\text{O}_3$:SiO$_2$**
After firing the mixture ratio in the second stage experiment at 1,200°C, an atmosphere of oxidation firing, electric furnace, the percentage of water absorption is between 0-0.88%, the color is white-cream, mature, and glossy surface all ratios of ingredients are shown as shown in Figure 5.

<table>
<thead>
<tr>
<th></th>
<th>A2-1</th>
<th>A2-2</th>
<th>A2-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>0.675</td>
<td>0.688</td>
<td>0.710</td>
</tr>
<tr>
<td>Al</td>
<td>0.015</td>
<td>0.015</td>
<td>0.015</td>
</tr>
<tr>
<td>Si</td>
<td>0.293</td>
<td>0.279</td>
<td>0.257</td>
</tr>
<tr>
<td>Na</td>
<td>0.714</td>
<td>0.816</td>
<td>0.921</td>
</tr>
<tr>
<td>B</td>
<td>0.026</td>
<td>0.027</td>
<td>0.027</td>
</tr>
<tr>
<td>Ca</td>
<td>7.124</td>
<td>7.085</td>
<td>7.150</td>
</tr>
<tr>
<td>Mg</td>
<td>10</td>
<td>9</td>
<td>8</td>
</tr>
</tbody>
</table>

**Table 1: Mixture Ratios**

From the results of the second stage, choose a formula No. A2-1 mix ratio consisting of Ball Clay 20%, Potassium Feldspar 30%, Quartz 50%, Whiting 12%, Dolomite 0.5%, Borax 0.5%, Colemanite 0.3%, and Soda Ash 0.2%. The Empirical Formula is shown in the form of the number of moles of oxide as follows:

0.293 K₂O 0.714 Al₂O₃ 7.124 SiO₂
0.017 Na₂O 0.026 B₂O₃
0.675 CaO
0.015 MgO

The results of surface characterization at particle level were analyzed by Scanning Electron Microscope (SEM) (Figure 6) and elemental composition was measured by Energy Dispersive X-ray Spectroscopy (EDS/EDX) (Figure 7) of the experimental body and Cone No.5.
Figure 6. SEM images at 100x, 1000x and 2000x
Table 1. Elemental composition of the experimental body and Cone No.5

<table>
<thead>
<tr>
<th>Element</th>
<th>Elemental composition of the experimental body</th>
<th>Elemental composition of Cone No.5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weight %</td>
<td>Atomic %</td>
</tr>
<tr>
<td>Si</td>
<td>37.83</td>
<td>30.79</td>
</tr>
<tr>
<td>O</td>
<td>35.06</td>
<td>50.10</td>
</tr>
<tr>
<td>Al</td>
<td>10.93</td>
<td>9.26</td>
</tr>
<tr>
<td>Ca</td>
<td>8.18</td>
<td>4.67</td>
</tr>
<tr>
<td>K</td>
<td>4.51</td>
<td>2.64</td>
</tr>
<tr>
<td>Na</td>
<td>1.88</td>
<td>1.87</td>
</tr>
<tr>
<td>Fe</td>
<td>1.60</td>
<td>0.66</td>
</tr>
<tr>
<td>C</td>
<td>0.01</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Figure 7. Elemental composition from EDS/EDX analysis
According to the percentage of elemental composition of body from EDS/EDX analysis according to Figure 8, it was found that the experimental body and Cone No.5 had the highest ratio of silica (Si) (30.79 and 38.13). Silica is obtained from the main raw material, Quartz (SiO2), which has the property to make the product durable, strong, not bend, shrink less. In addition, Ball Clay (Al2O3.2SiO2.2H2O), and Potassium Feldspar (K2O.Al2O3.6SiO2) are the main raw materials for making ceramic body, providing Silica and Alumina, and is an element that increases the adhesion of the body.

The filler material, such as quartz, an important role in ceramic body, to additional strength by reducing porosity. It does not react at low temperatures and forms a highly viscous liquid at very high temperatures firing [22].

For the alkaline group, Calcium (Ca) was found in the experimental body and Cone No.5 the highest (13.68 and 9.26). Calcium was obtained from Whiting (CaCO3), Dolomite (CaMg(CO3)2), Colemanite (2CaO.3B2O3.5H2O). There are also similar amounts of Potassium (K), and Sodium (Na). Ferric (Fe) is found in the elemental composition of both species. If the amount of ferric in the raw material is higher than 1%, it can cause color when mixed into the clay, it will turn brown after firing. If the ferric content is more than 1.2%, the clay will be red. Ferric is generally tainted from Ball Clay. It may be in the form of Hematite (Fe2O3) which will make the body red, or Limonite (FeO(OH)-nH2O) will give the body a yellow or brown color, which can reduce the temperature of liquid phase formation [23]. Oxides in this alkali act as a flux to reduce the temperature of the firing, and contributes to the increase of the glass phase.

The process of this study was a single firing process. While firing organic matter is burned, these substances should be completely dissolved before the alkali particles are melted. Otherwise it will cause the problem of surface bubbles, including in the cooling process of the product [24]. If considering the porosity characteristics of the ceramic body, it was found that the porosity characteristics were similar at % absorption equal to 0, but the surface defects caused by the forming of the body texture were found.

V. CONCLUSION AND RECOMMENDATION
The optimum mixture ratio of glossy ceramic body for forming without glaze is formulated as percentage of raw material consisting of 3 main raw materials: Ball clay 20%, Potassium Feldspar 30%, Quartz 50%, and addition raw material of 5 types, namely Whiting (12%), Dolomite 0.5%, Borax 0.5%, Colemanite 0.3%, and Soda ash 0.2%. Or write in the number of moles of oxides as follows: K2O 0.293 mole, Na2O 0.017 mole, CaO 0.675 mole, MgO 0.015 mole, Al2O3 0.714 mole, B2O3 0.026 mole, and SiO2 7.124 mol. The resulting ceramic body has medium to high toughness, after firing at 1,200°C (Orton pyrometric cone no.5), oxidation firing atmosphere, and electric furnace: Its surface is glossy, white-cream color, and has a water absorption of 0.00 percent. It can be used to form products both by hand forming and hand press plastic clay into plaster molds.
For the application of formulations in the production of ceramics, the properties of different raw materials even from the same source. Therefore, a conversion from the empirical formulas to the composition of the raw material is necessary before use that can change the types of raw materials in the alkaline group with water soluble properties, such as borax, colemanite, and soda ash to frit before. In addition, the reduction firing atmosphere helps to increase the whiteness of the ceramic clay.

VI. REFERENCES

