The effect of sintering temperature on the mechanical properties of ceramic

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Abstract The purpose of this research is to utilize natural resources in the form of clay and white sand in ceramics formation and to determine the effect of sintering temperature on the mechanical properties of the ceramics (compressive strength, thermal shrinkage and porosity) made from clay and silica sand (SiO$_2$) with a temperature variations. Ceramic formation used a mixture of clay and silica sand (SiO$_2$) with a ratio of 70%: 30%, then mold and compacted them using a hydraulic press to a pressure of 5 Mpa. The samples were then heated in a furnace at temperatures of 700°C, 800°C and 900°C for 3 hours. The results of the calculation of mechanical properties show that all samples meet SNI standards and the ceramic that has the best quality is the ceramic sintered at a temperature of 900°C because it has the highest compressive strength, low thermal shrinkage and low porosity of 21.09 Mpa, 0.680% and 17.92 %, respectively.

1. Introduction
Ceramics are composite materials that have better resistance to high temperatures and corrosion than super alloys and have brittle properties. One method for analyzing the mechanical properties of ceramics is sintering [1]. The sintering stage plays an important role in determining the properties of ceramics. Sintering is the process of compaction of a batch of powders at high temperatures, close to their melting point, resulting in changes in microstructure such as a reduction in pore number and size, grain growth, increased density and volume shrinkage. It is due to the fact that the particles will be arranged more tightly [2]. In research conducted by Haryanti et al. [3] regarding the effect of sintering temperature on the mechanical properties of ceramics using clay and rice husk ash, they show that the higher sintering temperature, the higher compressive strength value of a ceramic. It shows that the higher the sintering temperature, the better the quality of the ceramic.

Another aspect that affects the strength of ceramics is the composition of the additive in the form of a fuser and a filler component. Filler and fuser that are often used are materials that contain silica. Quartz sand is one of the natural materials which has a high enough silica content [4]. Silica Mineral can be obtained from vegetable silica, mineral silica, and crystalline synthesis silica. Quartz sand, which is mineral silica, is often found in mining areas [5]. The potential for quartz sand is also found in Central Sulawesi, precisely in Pasir Putih Village, Pamona Selatan District, Poso Regency [4, 6].

Apart from silica, the main ingredient in ceramics is clay [7, 8]. The clay used in this study is clay originating from the village of Posona, Kasimbar District, Parigi Moutong Regency. Some people in Posona village work as brick makers. This research reports on ceramic formation and determines the effect of sintering temperature on the mechanical properties of ceramics (compressive strength, thermal shrinkage and porosity) made of clay and silica sand (SiO$_2$) with temperature variations.
2. Research methods

2.1 Ceramic formation
Silica sand was obtained from Pasir Putih Village, Pamona Selatan District, Poso Regency and clay obtained from Posona Village, Kasimbar District, Parigi Moutong District. The first stage is washing the sand to separate impurities from the sand, grinding using a mortar to smooth the sand and sifting to obtain a uniform or equal grain size. Next is to separate the clay from the dirt by sieving the clay after drying for several days. Next, the formation of ceramics with a variation of mixing the main ingredients (clay) and additional materials (silica sand) with a composition of 70% of clay and 30% of silica sand. Silica sand with mixed clay was put into a cylinder mold with a diameter of 2 cm, and a height of 4 cm then pressed them using a hydraulic press which is given the pressure of 5 MPa on each sample. The sample heating process is the final stage in the manufacture of ceramic products. The heating process is carried out using a furnace at various temperatures, namely at 700 °C, 800 °C, and 900 °C for 3 hours. In this process, the ceramics will undergo physical changes that make the ceramics can not be destroyed by water.

2.2 Sample testing phase

2.2.1 Thermal shrinkage
Sample testing which includes testing for thermal shrinkage, compressive strength and water porosity. Ceramic thermal shrinkage testing was conducted to obtain the amount of shrinkage that occurs in ceramics after burning or heating. Samples were heated using a furnace with temperature variations of 700°C, 800°C and 900°C for 3 hours. Then calculate the volume loss using the equation [9]:

\[ SB = \frac{V_1 - V_2}{V_1} \times 100\% \]  

\( SB \) = Thermal shrinkage (%)  
\( V_1 \) = Volume before burning (m³)  
\( V_2 \) = Volume after burning (m³)

2.2.2 Compressive strength
The compressive strength test is carried out using a TNM type TN20MD tool, and the compressive strength value is calculated using the following equation [10]:

\[ P = \frac{F}{A} \]  

\( P \) = Compressive strength (MPa)  
\( F \) = Force (N)  
\( A \) = Cross-sectional area (m²)

2.2.3 Porosity test
Porosity is water absorption property by the body of the ceramic object or the density level of the ceramic object after burning. Ceramic porosities are calculated using the following equation [9]:

\[ \text{Porosity} = \frac{\text{Wet mass} - \text{Dry mass}}{\text{Dry mass}} \times 100\% \]  

3. Result and discussion

3.1 Thermal shrinkage
Burning process in ceramics will cause shrinkage of the ceramic body. Shrinkage occurs because clay particles fill the places left by water due to the evaporation process during combustion. A standard value for Thermal Shrinkage is less than 2.5% [11].
Table 1. Ceramic thermal shrinkage

| No | samples | temperature | thermal shrinkage (%) | Δ        |
|----|---------|-------------|-----------------------|----------|
| 1. | SB 1    |             | 0.689                 |          |
| 2. | SB 2    | 700°C       | 0.678                 | 0.0032%  |
| 3. | SB 3    |             | 0.686                 |          |
| 4. | SB 1    |             | 0.679                 |          |
| 5. | SB 2    | 800°C       | 0.678                 | 0.0003%  |
| 6. | SB 3    |             | 0.679                 |          |
| 7. | SB 1    |             | 0.685                 |          |
| 8. | SB 2    | 900°C       | 0.680                 | 0.0016%  |
| 9. | SB 3    |             | 0.680                 |          |

Table 4 showing that the measurement results of ceramic shrinkage with temperature variations of 700 °C, 800 °C, and 900 °C have met the Indonesian Standard SNI (under 2.5%) [11]

3.2 Compressive Strength

Table 2 Ceramic compressive strength

| No  | samples | temperature | compressive strength (Mpa) | Δ             |
|-----|---------|-------------|-----------------------------|---------------|
| 1.  | KT 1    |             | 14.95                       |               |
| 2.  | KT 2    | 700°C       | 14.06                       | 0.3787 Mpa    |
| 3.  | KT 3    |             | 13.67                       |               |
| 4.  | KT 1    |             | 15.56                       |               |
| 5.  | KT 2    | 800°C       | 8.40                        | 2.4311 Mpa    |
| 6.  | KT 3    |             | 15.82                       |               |
| 7.  | KT 1    |             | 17.18                       |               |
| 8.  | KT 2    | 900°C       | 20.01                       | 1.1657 Mpa    |
| 9.  | KT 3    |             | 21.09                       |               |

Table 2 present the compressive strength of the samples, which showing that all ceramics have a value above 10 Mpa in accordance with the Indonesian National Standard. The greater the compressive strength of the ceramic, the greater the force required to break the ceramic [12]

3.3 Porosity

Porosity testing is carried out to determine the density of ceramic after burning by immersing the ceramic in water for 24 hours. The soaking process is done to measure what percentage of water was absorbed into the ceramic. The results of porosity calculations can be seen in Table 3 below.
Table 3. Ceramic porosity

| No. | samples | temperature | porosity (%) | $\Delta$  |
|-----|---------|-------------|--------------|-----------|
| 1.  | P 1     |             | 18.15        | 0.6572%   |
| 2.  | P 2     | 700°C       | 20.21        |           |
| 3.  | P 3     |             | 18.34        |           |
| 4.  | P 1     |             | 18.71        | 0.2817%   |
| 5.  | P 2     | 800°C       | 18.68        |           |
| 6.  | P 3     |             | 17.85        |           |
| 7.  | P 1     |             | 17.03        | 0.6055%   |
| 8.  | P 2     | 900°C       | 15.83        |           |
| 9.  | P 3     |             | 17.92        |           |

Table 3 showing that the ceramic that absorbs the most water is the sample P2 which has a porosity value of 20.21% and the ceramic that absorbs the least water is the P2 ceramic sample at 900 °C with a porosity value of 15.83%. These results are in accordance with the literature of Amaryllis (2008), that pores in ceramics greatly affect water absorption, the more pores, the more water absorption. When the clay is burned at temperatures over 800 °C, several changes will occur, for example, the clay becomes harder when it cools and becomes impermeable. The clay has undergone a vitrification process . This vitrification process is accompanied by volume shrinkage, the higher the temperature, the greater the shrinkage but, the lower the porosity. The higher the temperature, the lower the absorption capacity due to the decrease in pore volume [12].

4. Conclusion
Sintering temperature greatly affects the mechanical properties of ceramics, such as ceramics given a temperature of 900 °C which has a compressive strength value that reaches 21.09 MPa, while the best ceramic shrinkage and porosity values are at a temperature of 800 °C.

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