

## EFFECT OF DIFFERENT SINTERING TEMPERATURES ON THE MECHANICAL PROPERTIES OF PORCELAIN

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### ABSTRACT

**Objective:** This study investigates the effect of different sintering temperatures on the mechanical properties of porcelain, with particular attention to modulus of rupture and microhardness. The main objective of this research is to determine how varying sintering temperatures (800°C, 900°C, 1000°C, and 1100°C) influence these mechanical properties and to identify the optimal temperature conditions for achieving maximum strength and hardness.

**Research Method:** Porcelain slip obtained from Claytan, with a specific gravity of 1.8, was poured into molds, dried, and sintered at four different temperatures. The sintered samples were tested for modulus of rupture using a standard bending test and for microhardness using a Mitutoyo Vickers hardness tester under a load of 0.5 kg.

**Findings:** The results indicate that the modulus of rupture increases steadily with rising temperature, reaching its highest value at 1100°C, which demonstrates that this temperature promotes optimal densification and bonding. In contrast, the microhardness results reveal a different trend, with the highest hardness achieved at 1000°C, followed by a slight decrease at 1100°C. This reduction may be attributed to grain coarsening or excessive vitrification that weakens resistance to localized deformation. Overall, the findings confirm that sintering temperature has a direct and significant impact on the mechanical performance of porcelain.

**Originality:** The originality of this study lies in identifying 1000°C as the most effective temperature for enhancing hardness and 1100°C as the optimal temperature for maximizing flexural strength.

**Keywords:** Porcelain, Sintering Temperature, Mechanical Properties, Modulus of Rupture, Microhardness.

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### 1. INTRODUCTION

Porcelain, commonly referred to as triaxial porcelain, is classified as a vitrified whiteware characterized by its translucency in thin sections, impermeability to liquids, and high mechanical strength. It is typically produced from a refined mixture of kaolin, quartz, and feldspar, following a triaxial composition that generally consists of approximately 50% clay, 25% flux, and 25% filler.

One of the most important factors that governs the quality of porcelain is the sintering process, in which particles consolidate at high temperatures below the melting point through solid-state diffusion. This process not only enhances densification and bonding but also reduces porosity and improves the microstructure, ultimately influencing the overall performance of porcelain. During sintering, solid bonds are formed between particles, reducing surface energy through the minimisation of free surfaces. This process also contributes to grain growth, which partially eliminates grain boundaries, while simultaneously reducing pore volume, resulting in a more compact mass. The temperature required to achieve such bonding depends on the characteristics of the starting materials and the particle size distribution.

Mechanical testing plays a crucial role in evaluating the quality of sintered porcelain. Properties such as flexural strength, hardness, and fracture resistance are

highly sensitive to changes in sintering temperature, as temperature variations directly affect pore elimination, grain growth, and the degree of densification. An inappropriate sintering temperature may lead to incomplete bonding or excessive grain growth, both of which can compromise the mechanical performance of the final product.

Therefore, studying the effect of different sintering temperatures on the mechanical testing of porcelain is essential to identify the optimum condition that yields high-performance materials. This research focuses on analysing the mechanical behaviour of Claytan porcelain subjected to varying sintering temperatures, with the aim of producing porcelain that meets the required industrial standards.

## **2. LITERATURE REVIEW**

Porcelain fulfills diverse roles in contemporary science, engineering, and daily applications. As a technical material, it exhibits exceptional properties such as high mechanical and electrical strength, chemical inertness, and resistance to thermal shock and spalling, which are primarily attributed to its composition of naturally occurring minerals and advanced processing techniques (Misra & Misra, 2022).

Research on porous ceramics fabricated from clay and organic additives such as banana peel powder has demonstrated the importance of sintering within the 900°C–1100°C range. At 900°C, samples exhibited incomplete densification with relatively high porosity, while those sintered at 1100°C showed significant improvements in mechanical strength and microstructural uniformity (Prastyo et al., 2019). These findings confirm that sintering within this specific temperature range is critical for achieving desirable mechanical properties.

Similarly, studies on zirconia-based ceramics provide further insight into the role of sintering temperatures between 800°C and 1000°C. A study by Mu (2024) highlighted that increasing the sintering temperature enhanced densification and flexural strength up to a critical threshold, after which abnormal grain growth resulted in a decline in mechanical performance. This demonstrates that optimizing sintering conditions is necessary to balance porosity reduction with controlled grain growth.

Further research on ceramic sintering corroborates these findings. A study on mullite ceramics, for instance, found that the optimal density and properties were achieved at a specific temperature of 1175°C, reinforcing the idea that different material compositions require specific conditions for peak performance (Jalaluddin et al., 2024). Additionally, research on ceramics made from clay and silica sand showed that the best mechanical properties were achieved at a sintering temperature of 900°C (Jalaluddin et al., 2024). These findings all confirm that sintering temperature is a crucial variable that must be optimized to achieve the desired mechanical properties for different types of ceramic materials.

### **2.1 DENSIFICATION**

The densification of a particulate ceramic is technically referred to as sintering. Scientific understanding and control of sintering were only developed during the past 60 years. Today sintering is studied by plotting graph of density, porosity or shrinkage data as a function of time and by actual examination of the microstructure at various stages of sintering using equipment such as scanning electron microscopy or field emission scanning electron microscope (Richerson & David, 2006).

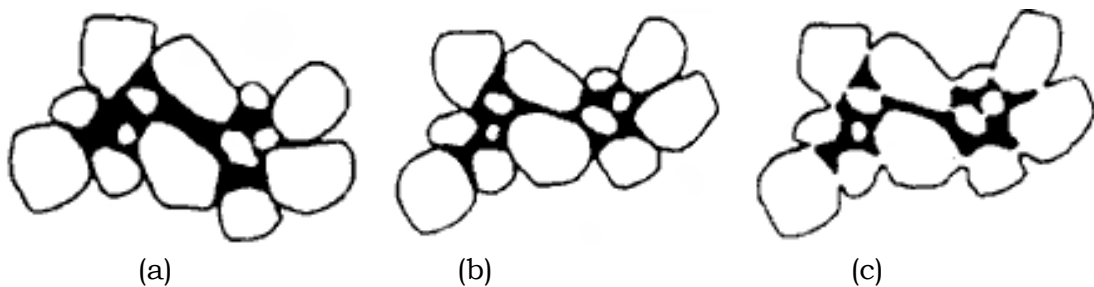
### **2.2 SINTERING**

Sintering is considered one of humanity's earliest technological advancements, originating in prehistoric times with the firing of pottery. It is a thermal processing technique used to produce materials and components with controlled density from metal or ceramic powders. The fundamental mechanisms involved in sintering are densification and grain growth, which occur as particles bond under elevated temperatures (Richerson, 2006).

During sintering, the ceramic green body undergoes significant changes in size and shape at the grain and pore level. Initially, the porous network transforms, breaking into individual pores that may appear spherical within grains or cylindrical along grain boundaries. The elimination of porosity results in increased density, a process referred to as densification. Conversely, coarsening occurs when pores change shape without a corresponding increase in density (Rahaman, 2007).

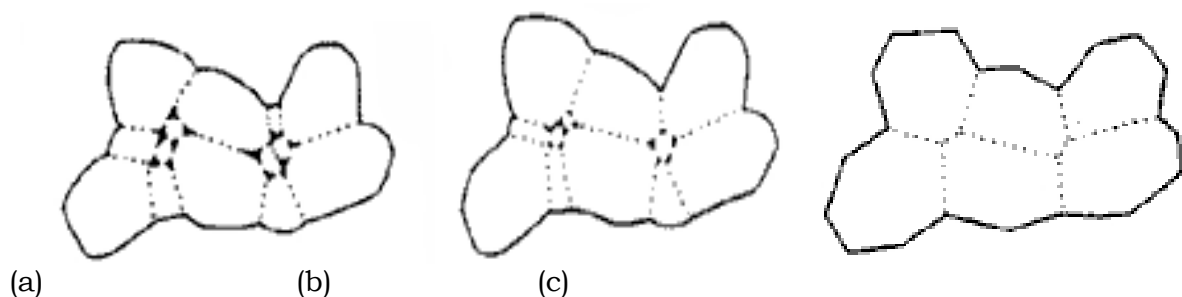
Porcelain composition is adjusted to facilitate forming and optimize firing behavior. As temperature rises, material from various sources within the green body flows to fill interparticle pores, and the deformed particles are termed grains. Sintering typically progresses through three stages: initial, intermediate, and final (Richerson & David, 2006). The initial stage involves particle rearrangement and the formation of necks at contact points, where bonding occurs due to material transport driven by surface energy gradients (Richerson & David, 2006).

Figure 1 illustrates the initial stage of sintering, which is characterized by the rearrangement of particles and the formation of initial necks at their contact points. At this stage, bonding occurs at these contact regions, where material transport is most active due to the high surface energy present (Guillon et al., 2023; Li et al., 2025).



**Figure 1:** Changes during the initial stage of sintering, (a) Starting particles, (b) rearrangement, and (c) neck formation (Richerson & David, 2006).

Figure 2 illustrates the final stage of sintering, which is characterized by the elimination of residual porosity primarily through vacancy diffusion along grain boundaries. This process is facilitated by grain boundary movement and controlled grain growth. However, as grains enlarge, pores tend to become isolated from the boundaries, reducing the likelihood of their removal. Therefore, regulating grain growth is essential to maximize porosity elimination and achieve optimal material density (Guillon et al., 2023; Li et al., 2025).



**Figure 2:** Changes during the final stage of sintering (a) Grain growth with discontinuous pore phase, (b) grain growth with porosity reduction, (c) grain growth with porosity elimination (Richerson & David, 2006).

### 3. METHODOLOGY

The primary raw material employed in this study was porcelain obtained from Claytan, a well-established manufacturer of tableware. Prior to casting, the porcelain slip was subjected to a viscosity test using a hydrometer. The slip, with a specific

gravity of 1.8, was subsequently poured into molds and allowed to solidify to form the test specimens. Thereafter, the specimens underwent a sintering process at four different temperatures in order to identify the most suitable and optimal firing temperature for the produced material. The influence of sintering temperature was then analyzed. The samples preparation in this study will be carried out as outlined in the flowchart shown in Figure 3.

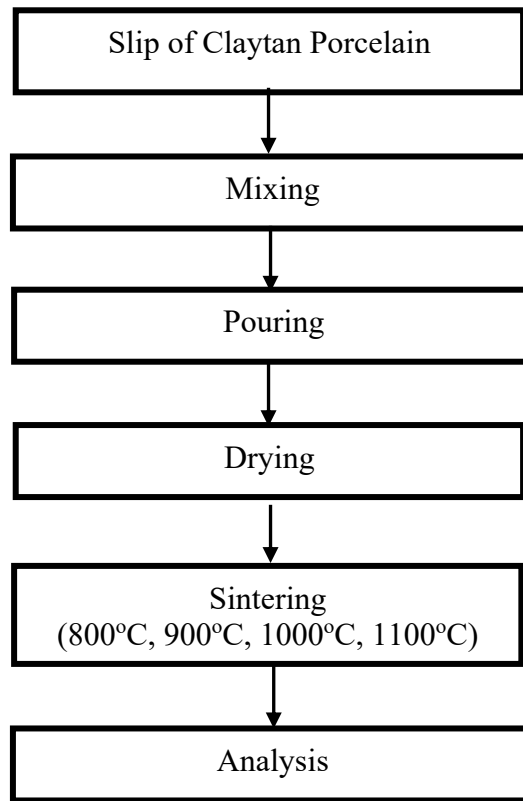
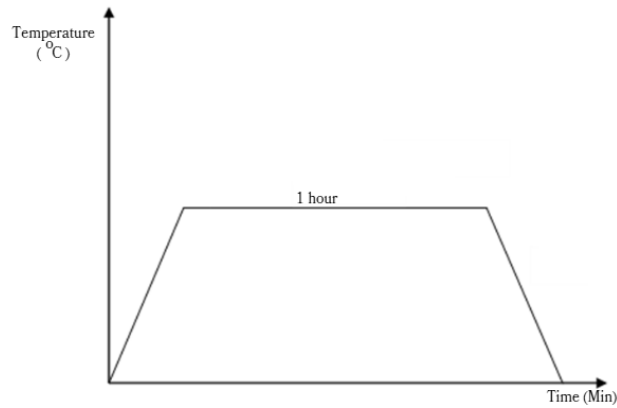


Figure 3. Sample preparation

The slip was first subjected to a mixing process to ensure homogeneity. It was then poured into molds and left to dry until the specimens solidified. Subsequently, the dried samples underwent a sintering process at four different temperatures, namely 800°C, 900°C, 1000°C, and 1100°C, to study the influence of firing temperature. Finally, the sintered specimens were subjected to analysis to evaluate their mechanical properties.

The green bodies were then sintered in an electrically operated laboratory furnace at four different temperatures, 800°C, 900°C, 1000°C and 1100°C respectively with 1 hour soaking time. The process of sintering was done by using the thermal profile as shown in Figure 4 below. One purpose of soaking time is to achieve uniform temperatures on the inside and outside of the pieces. Other benefits include the smoothing out of surfaces to get rid of pin holes or craters in the surface. This process will further enhance the mechanical properties and strength of ceramic components. These improvements were due to the formation of a bond between the ceramic particles and the occurrence of solidification



**Figure 4:** Thermal profile of sintered sample

The Standards used in this study is in accordance with the standards of the American Society Testing manual and Materials (ASTM). Standardized ASTM testing standards C1327 is a procedure used in the Vickers Micro hardness test on ceramic materials.

Modulus of rupture of the sintered samples was performed using a Universal testing machine, HYK-500B Digital Electricity (three point bending), as shown in Figure 5. By following the standard procedure, the sample is placed on two supports within 120 mm of each other. The force applied to the sample and the resulting broken power readings are taken and recorded in the Table 1.

**Table 1:** Modulus of rupture (MPa), at different sintering temperatures (°C)

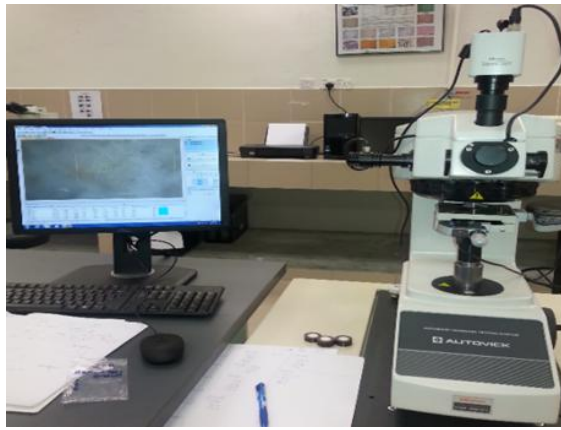
Sintering Temperature (°C)	Modulus of Rupture (MPa)
800	4.5
900	10.8
1000	11.5
1100	15.8



**Figure 5:** Equipment for MOR

**Table 2:** Micro Hardness (HV) at Different Sintering Temperature (°C)

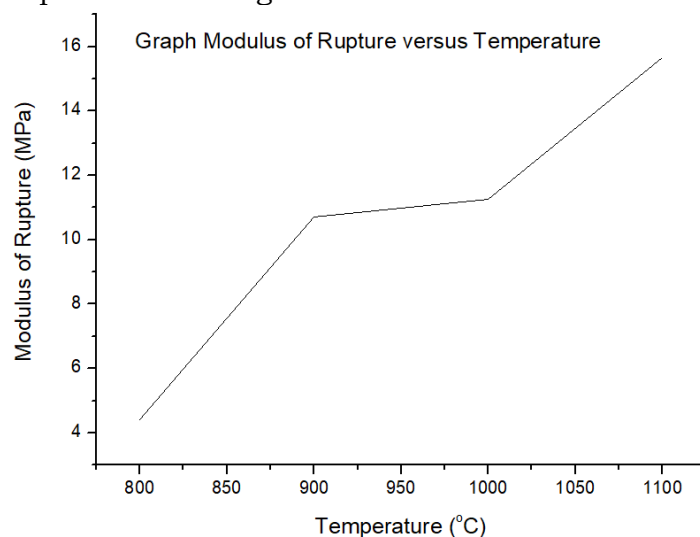
Sintering Temperature (°C)	Micro Hardness (HV)
800	106.4
900	111.53
1000	141.36
1100	138.43



**Figure 6:** Vickers Micro Hardness Testing Machine

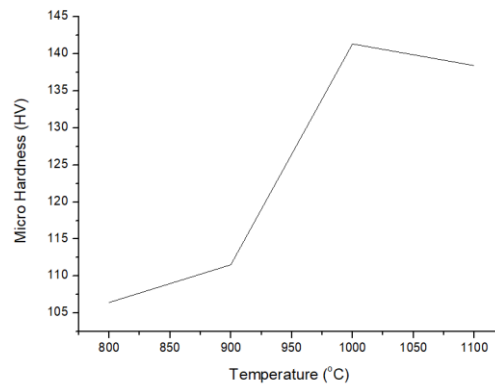
#### 4. RESULT AND DISCUSSIONS

The relationship between sintering temperature and the modulus of rupture (MOR) of porcelain samples is illustrated in Figure 7. At 800°C, the MOR recorded was the lowest, approximately 4.5 MPa, which reflects insufficient particle bonding and limited densification during the sintering process. When the temperature was increased to 900°C, the MOR showed a significant improvement, reaching around 10.5 MPa. This increase indicates that higher temperature enhances densification and strengthens the interparticle bonding.



**Figure 7:** Relationship MOR (MPa) and Temperature (°C)

At 1000°C, the MOR value increased slightly to about 11 MPa. The minimal increment observed suggests that the densification process had started to stabilize, resulting in only a marginal improvement in mechanical strength. However, when the sintering temperature reached 1100°C, the MOR rose markedly to nearly 16 MPa, representing the highest value obtained in this study. This sharp increase demonstrates that 1100°C provides the most effective densification, leading to significant enhancement in the strength of the porcelain specimens.



**Figure 8:** Relationship Between Micro Hardness (HV), and Temperature (°C)

The variation of microhardness with respect to sintering temperature is presented in Figure 8. At 800°C, the microhardness of the porcelain specimen was relatively low, approximately 106 HV, indicating weak bonding due to insufficient densification. When the sintering temperature was increased to 900°C, the microhardness rose slightly to about 111 HV, showing that densification had improved, although the strengthening effect remained modest.

A significant increase was observed at 1000°C, where the microhardness reached approximately 141 HV. This sharp increment suggests that at this temperature, the porcelain samples experienced substantial densification and stronger interparticle bonding, resulting in enhanced mechanical resistance to localized deformation. However, at 1100°C, the microhardness value decreased slightly to around 138 HV. This minor reduction may be attributed to the onset of grain coarsening or excessive vitrification, which can reduce hardness despite higher firing temperatures.

## 5. CONCLUSIONS

The findings of this study highlight the significant influence of sintering temperature on the mechanical properties of porcelain. Both the modulus of rupture and microhardness values increased with rising sintering temperatures, although their optimal values occurred at different ranges.

For the modulus of rupture, the strength improved progressively with temperature, with the highest value obtained at 1100°C, indicating that this temperature provided the best densification and mechanical strength. In contrast, the microhardness exhibited a sharp increase at 1000°C, reaching its peak value before showing a slight reduction at 1100°C, possibly due to grain coarsening or excessive vitrification.

In summary, the results suggest that 1000°C is the most effective sintering temperature for achieving maximum hardness, while 1100°C is optimal for maximizing the modulus of rupture. These findings demonstrate that careful selection of sintering temperature is crucial in optimizing the overall mechanical performance of porcelain.

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