THERMAL ANALYSIS OF CLAYTAN PORCELAIN WITH POTASSIUM FELDSPAR ADDITIONS

Mohd Azmi Zulkifli[1], Norhayati Mohd[2]

[12]Politeknik Ungku Omar, Ipoh, Perak

*Corresponding E-mel: azmizul@puo.edu.my

ABSTRACT

Objective: The objective of this study is to investigate the thermal behavior of Claytan porcelain blended with varying weight percentages of potassium feldspar using Thermogravimetric Analysis (TGA) and Differential Thermal Analysis (DTA). The study aims to understand how different feldspar compositions influence thermal stability, sintering behavior, phase transformations, and overall material performance.

Research Method: This experimental study analyzes Claytan porcelain mixed with different weight percentages of potassium feldspar. Thermogravimetric Analysis (TGA) was used to measure weight loss associated with thermal events, while Differential Thermal Analysis (DTA) was performed to identify endothermic and exothermic reactions during heating. Thermal changes, moisture evaporation, dehydroxylation, crystallization, and high-temperature phase transformations were evaluated to determine the influence of feldspar content on porcelain behavior.

Findings: The TGA results show early weight loss below 59 °C due to moisture evaporation and a more significant mass loss around 412 °C linked to chemical interactions between porcelain and potassium feldspar. Total weight loss is low (0.44%–0.52%), indicating excellent thermal resistance across all formulations. DTA results reveal endothermic peaks at ~56 °C (moisture removal), 510–515 °C (kaolinite dehydroxylation), and exothermic peaks at 967–981 °C (crystallization of kaolinite derivatives). Endothermic reactions above 1130 °C without weight loss suggest structural phase changes such as mullite and glassy phase formation. These results confirm stable thermal behavior and characteristic phase transitions essential for porcelain densification.

Originality: This study offers new insights into how varying additions of potassium feldspar influence the thermal stability, phase transformation behavior, and sintering performance of Claytan porcelain. By combining TGA and DTA results, the research provides a deeper understanding of the role of feldspar as a fluxing agent, contributing valuable information for optimizing porcelain formulations in industrial ceramic manufacturing.

Keywords: Claytan porcelain; potassium feldspar; thermogravimetric analysis; differential thermal analysis; thermal stability.

---

1. INTRODUCTION

Thermal analysis techniques such as Thermogravimetric Analysis (TGA) and Differential Thermal Analysis (DTA) are widely employed to study phase transformations, weight-loss behavior, and sintering kinetics in porcelain systems. TGA provides insights into weight-loss stages associated with dehydration and decomposition, while DTA identifies endothermic and exothermic reactions, including vitrification onset and phase transitions. These methods are essential for optimizing firing schedules and reducing energy consumption (Fuertes et al., 2022).

Dilatometry and hot-stage microscopy have also been used to determine melting behavior and glaze fusibility, particularly in feldspar-based porcelain glazes, where viscosity reduction and smooth surface formation. (Dumitru et al., 2024)

The study of weight changes and heat flow during controlled heating provides valuable insights into the decomposition process, structural water loss, and phase transitions of the ceramic system.

In particular, the presence of potassium feldspar is expected to affect the onset temperatures of mass loss, the formation of metakaolin from kaolinite, and the occurrence of exothermic and endothermic reactions at elevated temperatures. By analyzing the thermal behavior of porcelain with different potassium feldspar compositions, the relationship between feldspar content and thermal stability can be better understood, which is crucial for optimizing porcelain properties in industrial applications.

2. LITERATURE REVIEW

Porcelain is a triaxial ceramic system composed of kaolin, quartz, and feldspar. Hard porcelain, characterized by low feldspar and high kaolin content, requires higher firing temperatures and exhibits superior mechanical and chemical properties, making it suitable for industrial applications. Soft porcelain, with higher feldspar content, achieves vitrification at lower temperatures, making it ideal for decorative and domestic ware (Budnikov, 1964).

The phase composition and properties of porcelain depend on the interaction of kaolin, quartz, and feldspar at high temperatures, influenced by raw material proportions, chemical composition, particle size, and sintering conditions (Budnikov, 1964). Studies have shown that feldspar type and particle size significantly affect densification and thermal properties.

Feldspar, an anhydrous aluminosilicate, is the most abundant mineral group in the Earth's crust and plays a critical role in ceramic manufacturing due to its fluxing properties and contribution of alumina and silica to ceramic bodies. Its primary function is to lower the melting temperature during firing by forming a glassy phase, which enhances vitrification and mechanical strength of ceramics (Fuertes et al., 2022)

Studies have shown that feldspar type and particle size significantly affect densification and thermal properties. Sodium feldspar promotes earlier vitrification and higher bulk density, while K-rich feldspar enhances deformation resistance at elevated temperatures (Aydın Günbay et al., 2023; Kr., 2003).

2.1 STRUCTURE OF POTASSIUM FELDSPAR

Potassium feldspar ($KAlSi_3O_8$) is a key component in porcelain production due to its role as a fluxing agent and its contribution to the material's structural integrity. Structurally, it belongs to the feldspar group of aluminosilicate minerals and typically occurs in monoclinic or triclinic crystal systems, composed of potassium, aluminum, silicon, and oxygen (Common Minerals, n.d.).

In porcelain, potassium feldspar lowers the melting temperature during firing, facilitating vitrification and the formation of a glassy phase that binds other components such as kaolin and quartz. This process enhances the density, strength, and durability of porcelain while improving its translucency and surface smoothness (Formulators Inc, 2023).

2.2 COMPOSITIONS OF PORCELAIN

Figure 1 illustrates the typical compositional ranges of porcelain ceramics using a ternary diagram of kaolin, quartz, and feldspar. The diagram shows how different ceramic types occupy distinct regions based on their raw material proportions. Hard porcelain is positioned toward the kaolin-rich side, indicating its higher clay content and lower feldspar proportion, which requires higher firing temperatures and results in superior mechanical strength.

Soft porcelain lies closer to the feldspar-rich region, reflecting its higher flux content that promotes vitrification at lower temperatures. Stoneware and fine earthenware occupy intermediate zones with balanced proportions of clay and quartz, while dental ceramics are located near the feldspar apex, signifying their high flux content for enhanced translucency and glassy phase formation.

Chemical porcelain, on the other hand, is situated near the kaolin apex, emphasizing its high clay content for chemical resistance. This diagram highlights the critical role of raw material ratios in determining the thermal behavior, phase composition, and functional properties of porcelain ceramics (Buchel, 1989).

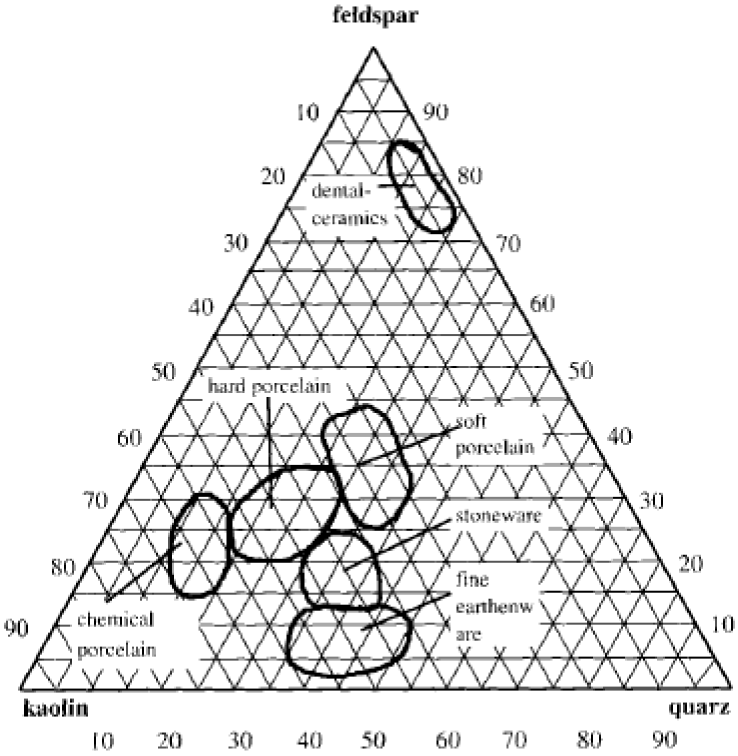


Figure 1: Typical Compositions of porcelain ceramic (Buchel, 1989)

Quartz plays a vital role in enhancing chemical resistance at typical commercial firing temperatures, which are generally below 1300 °C. Its presence helps minimize shrinkage, distortion, and warping during sintering, particularly when large amounts of viscous glass are formed. An inadequate amount of quartz can lead to poor glaze fit, resulting in defects such as crazing, whereas excessive quartz may cause cracking or fracture of the ceramic body (Ryan, 1978).

Feldspar is another essential raw material in traditional ceramic compositions. Budnikov (1964) explains that feldspar acts as a fluxing agent, functioning almost like a solvent for kaolin and quartz. Its effect depends on the relative proportions of these materials and the firing temperature achieved during processing. By lowering the melting point, feldspar facilitates the formation of a glassy phase, which is critical for densification and vitrification of porcelain bodies.

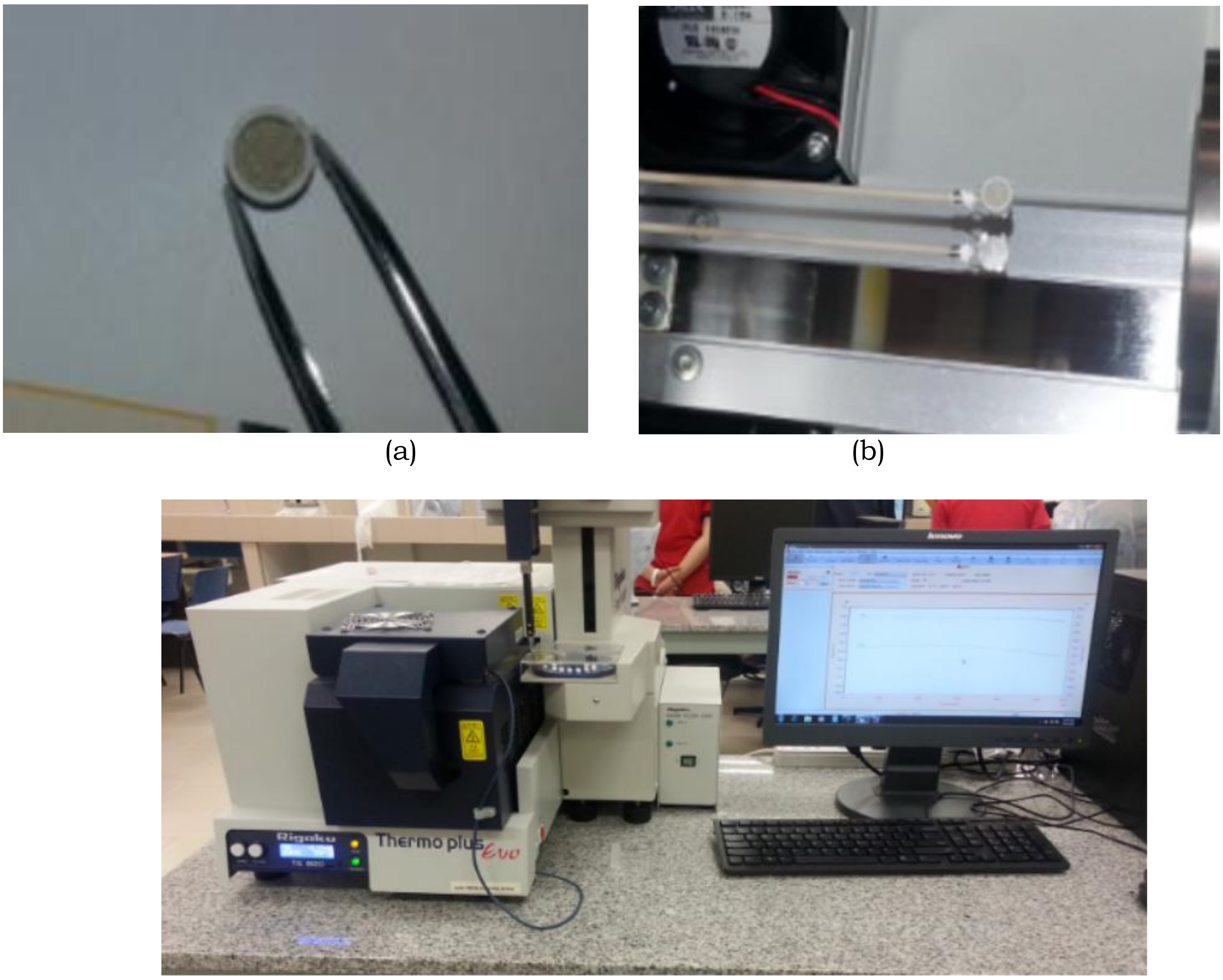
In whiteware ceramics, feldspar serves multiple purposes. It promotes the development of a glassy phase at relatively low temperatures and provides alkalis and alumina for glaze formation. The initial glassy phase typically forms through a ternary eutectic reaction, which significantly improves the strength, toughness, and durability of the ceramic body. These properties are essential for producing high-quality porcelain products that meet both functional and aesthetic requirements (Kyonke, 2007).

3. METHODOLOGY

Differential Thermal Analysis (DTA) and Thermogravimetric Analysis (TGA) were carried out on Claytan porcelain mixed with varying amounts of potassium feldspar powder using a Rigaku TG-DTA 8120 instrument from Japan. These tests aimed to observe weight changes and phase transformations during heating for samples containing 0 wt%, 2 wt%, 4 wt%, 6 wt%, 8 wt%, and 10 wt% potassium feldspar. The measurements were performed up to 1400 °C at a heating rate of 10 °C per minute in alumina crucibles.

For sample preparation, the materials were first ground into fine powder as shown in Figure 2(a), then placed into the sample holders illustrated in Figure 2(b). The procedure followed standard conditions in an air atmosphere, with calcined alumina serving as the reference material.

DTA was conducted using the Rigaku TG-DTA 8120 analyzer Figure 2(c)) under the same atmosphere. The TGA curve is presented from left to right, where the X-axis represents either time or temperature, and the Y-axis indicates weight in milligrams or weight percentage. From these curves, it can be inferred that heating a material leads to either an increase or a decrease in weight, depending on the thermal reactions involved.



(a) (b)

(c)

Figure 2: Thermo gravimetric (TGA) Instrument

Table 1 presents the compositions of Claytan porcelain blended with varying weight percentages of potassium feldspar, which were analyzed to investigate their thermal behavior.

Table 1: The samples analyzed.

Claytan Porcelain wt. (%)	Potassium Feldspar wt. (%)
100	0
98	2
96	4
94	6
92	8
90	10

4. RESULTS AND DISCUSSIONS

A typical TGA curve of a mixture of Claytan porcelain and potassium feldspar is shown in Figure 2. The weight drop profile exhibited all compositions of potassium feldspar, in the temperature range from 412°C to 626.73°C respectively. The TGA plot shows that as temperature is increased the sample loses weight and by about 626.73°C weight loss is complete for all formulation samples.

Overall, early mass loss occurs before 59° C. This is due to the moisture present in the mixture. In another observation, a significant mass loss at about 412° C is due to the reaction of Claytan porcelain and potassium feldspar. The average percentage of weight loss for 6wt% and 10wt% of potassium feldspar is 0.44%, for 2wt% and 8wt% is 0.52% and for 4wt% is 0.59%, while for 0wt% of potassium feldspar which is used as a reference, the weight loss is 1.14%.

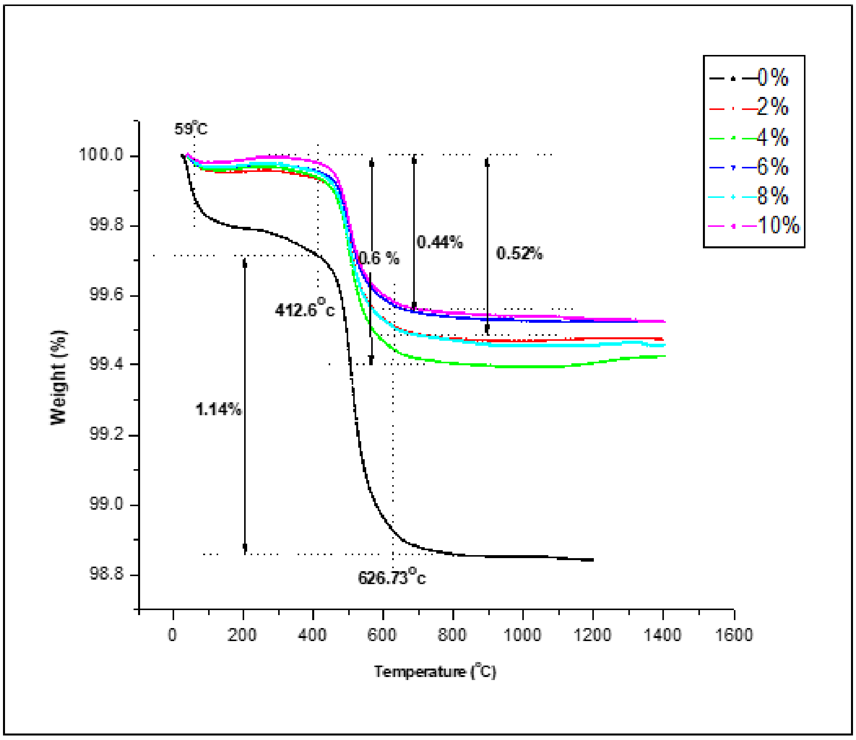


Figure 3: A Summary of TGA for different temperature and different ratio of potassium feldspar

Figure 3 shows the differential thermal analysis of the initial characteristic for 0wt%, 2wt%, 4wt%, 6wt%, 8wt% and 10wt% of potassium feldspar, respectively. The first endothermic peak reaction at 56°C is attributed to the evaporation of the adsorbed water. The second endothermic reaction reported by Carty, (1998) is attributed to the transformation of kaolinite to metakaolin ($Al2O3 \cdot 2SiO2$) with loss of structural water for all the compositions (except 8wt%) in the temperature range from 510°C to 515.23°C.

Exothermic peaks appeared at 970.14°C, 974.83°C, 981.08°C, 979.98°C and 967.47°C for 0 wt%, 2 wt%, 4wt%, 6wt% and 10 wt% of potassium feldspar respectively. These particular peak temperatures are typical of kaolinite thermal characteristics (Carty and Senapati, 1998).

The last endothermic peaks at temperature 1133.21°C, 1130.84°C, 1218°C, 1223.2°C, 1137.8°C and 1151.08°C for all compositions of potassium feldspar occur without weight losses.

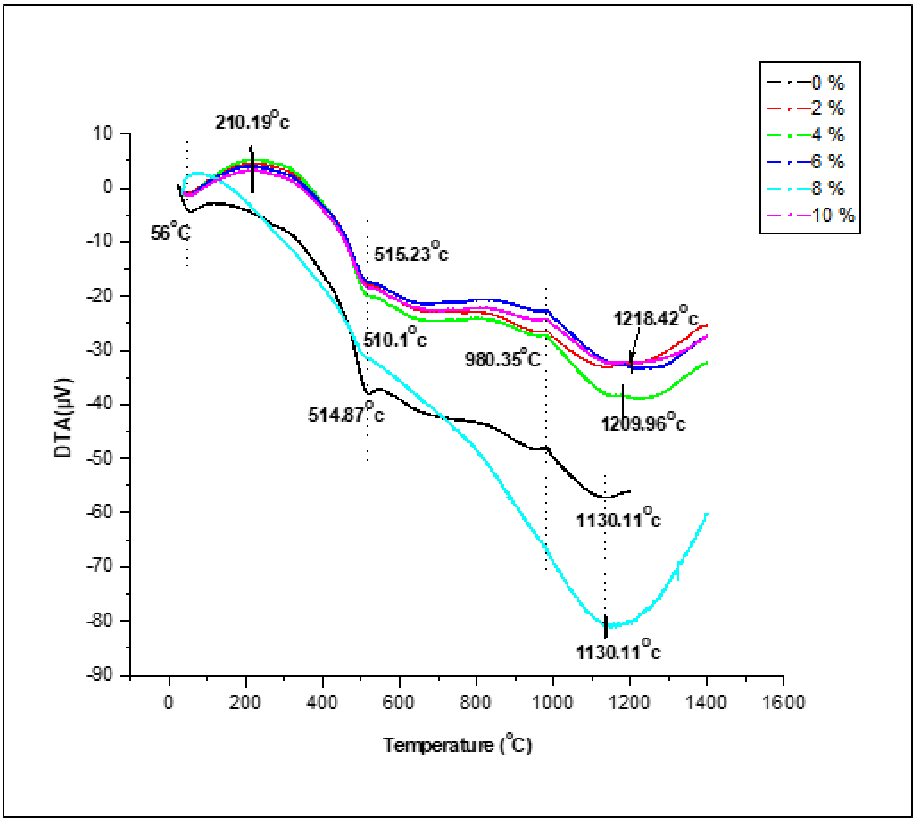


Figure 4: A Summary of DTA for different temperatures and different ratio of potassium feldspar

5. CONCLUSIONS

An initial mass reduction occurring before 59 °C is attributed to moisture evaporation. A notable weight decreases around 412 °C is linked to the interaction between Claytan porcelain and potassium feldspar. The overall weight loss remains minimal, averaging between 0.44% and 0.52% across all compositions, which suggests improved thermal stability.

Differential thermal analysis indicates the first endothermic peak at approximately 56 °C, corresponding to the removal of adsorbed water. A second endothermic event observed between 510 °C and 515.23 °C is associated with the conversion of kaolinite into metakaolin.

The sequence of chemical reactions during thermal treatment of Claytan porcelain with varying potassium feldspar content was examined using the combined DTA and TGA technique. Both compositions exhibited similar reaction stages up to

1399 °C, after which feldspar formed a eutectic melt and began to react. The findings are presented based on two factors: the influence of sintering temperature and the effect of potassium feldspar additions at 0 wt%, 2 wt%, 4 wt%, 6 wt%, 8 wt%, and 10 wt%.

REFERENCES

Budnikov, P. (1964). The Technology of Ceramics and Refractories. London: Edward Arnold Ltd. (n.d.). In Budnikov, P. (1964). The Technology of Ceramics and Refractories. London: Edward Arnold Ltd.

Buchel, K. H. (1989). Industrial Inorganic Chemistry. Wiley-VCH. (n.d.). In Buchel, K. H. (1989). Industrial Inorganic Chemistry. Wiley-VCH.

Claytan Oriental Ceramics. (2024). About US. Retrieved from https://www.claytantableware.com/pages/about-US. (n.d.). Claytan Oriental Ceramics. (2024). About Us. Retrieved From https://www.claytantableware.com/pages/about-us.

CyCookery. (2024). The Enduring Appeal of Claytan Dinnerware in Malaysia: A Tableware Tradition. Retrieved from https://cycookery.com/article/claytan-dinnerware-set-Malaysia/. (n.d.). In CyCookery. (2024). The enduring appeal of Claytan dinnerware in Malaysia: A tableware tradition. Retrieved from https://cycookery.com/article/claytan-dinnerware-set-malaysia/

Formulators Inc. (2023). The Power of Feldspar in Ceramics. Retrieved from https://formulatorsinc.in/blogs/ceramics/the-power-of-feldspar-in-ceramics. (n.d.). Formulators Inc. (2023). The Power of Feldspar in Ceramics. Retrieved From https://formulatorsinc.in/blogs/ceramics/the-power-of-feldspar-in-ceramics.

H, B., H, C., and A, S. (2015). Characterization of porcelain tableware formulation containing bentonite clay. *International Journal of the Physical Sciences*, *10*(1), 38–45. https://doi.org/10.5897/ijps2014.4218

Park, H., Yeo, J., Choi, J., Choe, G., Kim, G., Koh, Y., Yang, S., & Jung, Y. (2021). Ceramic green and fired body with a uniform microstructure prepared using living characteristics of photo-curable cycloaliphatic epoxide: Applicability of cycloaliphatic epoxide in photo-polymerization-based 3D printing. Journal of the European Ceramic Society, 42(2), 589–599. https://doi.org/10.1016/j.jeurceramsoc.2021.10.015