Possibility of obtaining Transparent Glaze from the Local clays of Qena Governorate

Rasha Fawzy Ahmed Abd Elrahem[1], Hamada Mohmed Abdelmotalib[2], Mohamed Ali Hassan[3], Ebrahim Desouky Abd–Elmawgoud[1]

[1]Art Education Department, Faculty of Specific Education, south valley university, Qena, 83521, Egypt

[2]Mechanical Power and Energy Engineering Department, Faculty of Engineering, Minia University, Elminia ,6115, Egypt.

[3]Mechanical Department, Faculty of Technology and Education, Sohag University, Sohag, Egypt

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Abstract

Glaze is a glassy layer used to cover surfaces of different ceramic products. It gives ceramic surface hardness and high resistance to chemical and abrasion which contributes to enhancing the chemical and physical properties in addition to the aesthetics of the ceramic products. Production process of glaze is complex and expensive, as it requires accurate compositions of different materials most of which are expensive. herefore, the main aim of this study is to develop a transparent ceramic glaze from the Local clays of Qena Governorate. Three types of local clays used in this study were “Taffla” marl clay, “Hieba” Flood Clay, and Nile clay. The production processes were conducted at different combustion temperatures of 1000, 1050, and 1100°C using borax as alkaline fluxing agents at different ratios of 50%, 60%, and 70%. The glaze is produced only from the clay and fluxing agent without the need to add any former or bonding refractory materials which are common in traditional methods of glaze production. The required tests were carried out for clay and glaze to determine their different characteristics. Results showed that among the three products, the best results were achieved at combustion temperature of 1050°C and the highest alkaline fluxing agent ratio of 70%. Moreover, the obtained results demonstrated that the possibility of the production of transparent ceramic glaze directly from special types of clay without adding any other material which minimize effort, time glaze.

Keywords: Ceramics; Clay; Fluxing Agent; Transparent Glaze; Local Clays of Qena Governorate.

1. Introduction

Ceramics are commonly used in most of aspect of our daily life due to their excellent properties such as hardness, corrosion-resistance, brittleness, excellent insulators, and hold high temperatures. Different products of ceramics are used in many applications, mainly in the pottery, brick, glass, and tile industries. Moreover, they are used to make fiber optics, spark plugs, cooktops, artificial joints, and many other applications. Glaze is a main parameter in the production of ceramics because it makes pottery smooth, waterproof, hygienic, fashionable, mechanically stronger, chemical attack resistant, and luxurious[1, 2]. Ceramic glaze is a thin strong layer that being used over a body of ceramic and made from a mixture of different minerals and fused to a pottery body through combustion [3, 4] The first glazes were utilized in Egypt and the Near East since 1500 BCE and in the Western world, the lead glaze was utilized around the first century BCE. The glazed bricks were used around 2000 BCE in Lower Mesopotamia for building cladding [5]. Glaze composed from three major compositions, glaze former such as vitrified materials (i.e silica), the fluxing agent which decreases the melting temperature, and the bonding material which bond the glaze to the clay [6]. Depending on the heat treatment temperature and application, the glaze contains the mineral raw material or frit glaze [7]. In various applications, the main goal is to produce a transparent glaze on the ceramic material surface [8, 9]. A transparent glaze is widely used on the decorative layer to keep a good decorative impact by applying a smooth and easy and clean surface [10, 11]. Glaze transparency is achieved when the material has the ability to transmit large portions of incident electromagnetic radiation [12].

The preparation process of glaze should be achieved in a systematic way to avoid any problems, especially those resulting from the incorrect weighting of glaze compositions, mainly former and stabilizer materials. The incorrect portion of different glaze compositions can cause a loss of load for the entire kiln as well as reduce the quality of the produced glaze. The ceramic glazes can be prepared from a mixture of different natural materials using different compositions and techniques [13]. Several studies are concerned with glaze development using different raw materials and other additional compositions to enhance glaze properties [14-30]. Sungmin and Kangduk et al [14]used TiO_2 as a nucleating agent to apply $CaO–Al_2O_3–SiO_2–ZnO$ (CASZ)-based glass to crystallize the glaze. The titanite crystal phase was developed as the TiO_2 substitution increased and the glaze crystallinity rapidly increased. Additionally, with increasing the TiO_2 substitution glaze density increased. Samples without TiO_2 substitution had the lowest value of hardness, and this value rapidly increased with specimens containing TiO_2 substitution. A mullite-enhanced transparent glaze was prepared by **Y.uming** et al. [15]. The particles of mullite were used in the raw materials which melted into frit. The results indicated the dissolving of the mullite crystals into the melt and then reprecipitating during firing, composing a branched architecture that enhanced the collection of glass and mullite. The addition of mullite didn't affect the transparency of the glaze. **Jiexi** et al. [16] investigated the effect of bentonite on the enamel product performance and the glaze slurry suspension stability. The addition of 1 wt.% bentonite to the glaze slurry improved the glaze slurry's stability and the mechanical properties of the enamel products. Moreover, the addition of bentonite by 0.5 wt.% was optimal for improving the resistance to acid corrosion.

According to the literature, most of the studies focused on the development of glaze using different materials, namely a former, stabilizer, and flux agent. Therefore, the objective of the present work is to develop a novel transparent glaze. The glaze was prepared directly from clay and an alkaline fluxing agent without any other additions. The p Three types of low-cost clay formed in upper Egypt were used. The experiments were conducted at different combustion temperatures with different ratios of the fluxing agent.

2. Search aim:

Possibility of obtaining Transparent Glaze from the Local clays of Qena Governorate.

3. Search hypothesis:

Transparent glaze can be obtained from local clay in Qena Governorate.

4. Search parameters:

4.1 Clay:

clay (A) "Taffla" marl clay, From the western plateau in the village of Al Mahrousa "Ballas" in Qena Governorate. Clay (B) "Hieba" Flood Clay, From the eastern valley in the city of Qena. Clay (C) Nile, From the banks of the Nile in Qena Governorate.

4.2 fluxing agent:

alkaline fluxing agent "borax" ($Na_2B_4O_7$).

5. Materials and methods

5.1 Material

The samples used in this study are divided into two parts: the body which is made from prepared terracotta slabs and the glazed layer which is formed using three different types of clay. The materials used for glaze production shown in **Fig. 1** are “Taffla” marl clay, “Hieba” Flood Clay, and Nile clay referred to as clay (A), clay (B), and clay (C), respectively. These clays are located in Qena, Egypt at low cost. Therefore, the glaze production process will be inexpensive. Borax ($Na_2B_4O_7$) was used as an alkaline fluxing agent to reduce the melting temperature of the used material at different mixing ratios.

Fig. 1 (a). Digital photos with high resolution show the different types of clay used in this study.

2.2 Experimental methods

In order to prepare the frit, the clay sample was placed with the fluxing agent inside a crucible that has channels, and the mixture is exposed to a high temperature of 1050°C inside an oven until the mixture melts. The liquid mixture passes through the channel to the outside of the oven into a container of water**.** The mixture was converted into glass balls that were ground and converted to a powder called frit as shown in **Fig. 2**. The produced frit can be used as a glass coating material with low cost compared to other traditional production methods. The development of the new glaze formula is processed by the 9-grid coordinate method as shown in **Fig. 3** to organize and distribute proportions of the clays, fluxing agents (50, 60, and 70 wt.%), and combustion temperatures of (1000℃, 1050℃, and 1100℃), which enable the acquisition of the suitable formulas.

The three types of clay were kept in air and then soaked in water to get rid of excess organic matter and salts. This process continued three times, then the samples were dried and ground again, and sifted using an

ASTM 325 sieve (75µm mesh). The prepared clay was calcined using an electric oven at 600°C for 1 hour. The weight ratios of the glazes were prepared from the raw materials according to a 9-grid coordinate method as given in **Table 1**. Each type of clay used in the experiments was applied to the previously prepared terracotta slabs (50% ball clay and 50% kaolin, 4 cm in diameter, fired at 1000°C), then the samples were fired according to the specified burning degrees by an electric furnace.

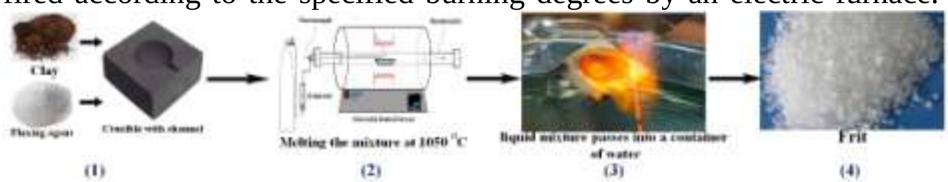


Fig. 2 Experimental procedure simulator of production of glaze frit: 1) clay mixture, 2) mixture melting, 3) liquid mixture passed in container of water, and (4) frit.

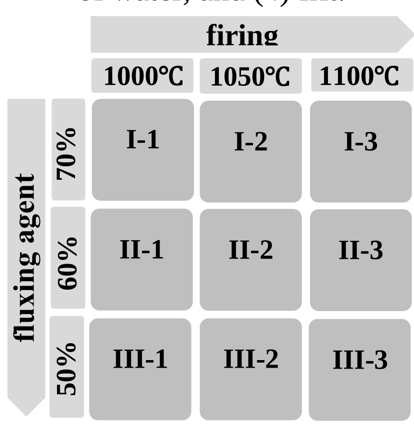


Fig. 3 Clay samples by 9-grid coordinate method.

Table 1. Clay samples by 9-box grid coordinate method.

	Clay%	Fluxing agents%	Firing Temperature		
			1000℃	1050℃	1100℃
Clay (A)	30%	70%	AI-1	AI-2	AI-3
	40%	60%	AII-1	AII-2	AII-3
	50%	50%	AIII-1	AIII-2	AIII-3

	Clay%	Fluxing agents%	Firing Temperature		
			1000℃	1050℃	1100℃
Clay (B)	30%	70%	BI-1	BI-2	BI-3
	40%	60%	BII-1	BII-2	BII-3
	50%	50%	BIII-1	BIII-2	BIII-3
Clay (C)	30%	70%	CI-1	CI-2	CI-3
	40%	60%	CII-1	CII-2	CII-3
	50%	50%	CIII-1	CIII-2	CIII-3

6. Results and discussion

6.1 clay analysis

The chemical composition of used clay and borax was carried out using X-Ray Fluorescence (XRF) as given in **Table.2**. The mineralogical analysis of clay was conducted using the X-Ray Diffractometer (XRD) as shown in **Fig. 4**. The XRF analysis of all used clay indicated that the percentage of SiO_2 which acts as a glaze former and show high percent for all the samples of clay. The analysis shows the presence of Al_2O_3 which acts as a stabilizer at a good percentage. Moreover, the test results indicate the presence of Fe_2O_3 which acts as a colorant, and K_2O, MgO, or CaO which act as fluxing agents. The loss of ignition (LOI) of clay A, B, and C was 0.109, 0.073, and 0.027, respectively.

In addition, the XRF analysis indicated that the content of K_2O in the clay samples ranging from 0.96 to 1.15 %, which can significantly reduce the temperature of samples and constructing it conducive to firing [31]. From another side, the highly ratios of SiO_2/CaO are evident in the Fired clay bodies which indicated appears the gehlenite as a new phase [32]. Previous studies have shown that reducing the rate of SiO_2/CaO the crystalline phase transforms from diopside to gehlenite, as established by XRD[33].The XRD patterns of clay samples (A, B, and C) are shown in **Fig. 4**. The figure indicates the presence of quartz (96-900-9667), coesite (96-900-7170), corundum (96-900-9672), boehmite (96-901-2251), lime (96-900-6743), magnetite-h (96-900-2333), periclase (96-901-3245), and brucite (96-900-2352) in clay samples A, B, and C, respectively. Both XRF and XRD demonstrated the good properties of different used clay giving them the ability to produce transparent good glaze without the need of adding other materials.

Table 2. The XRF analysis of clay and borax used in this study.

Raw materials	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	TiO_2	P_2O_5	SO3	K_2O	Cl	SrO	MnO	LOI
Clay (A)	40.14	34.59	12.23	6.652	1.48	1.09	1.02	0.99	0.96	0.49	0.14	0.08	0.109
Clay (B)	32.73	40.08	11.59	8.98	2.33	1.30	0.69	0.72	1.15	0.13	0.12	0.15	0.073
Clay (C)	0.497	57.57	21.87	14.37	0.67	2.49	0.53	0.61	0.94	0.09	-	0.24	0.027

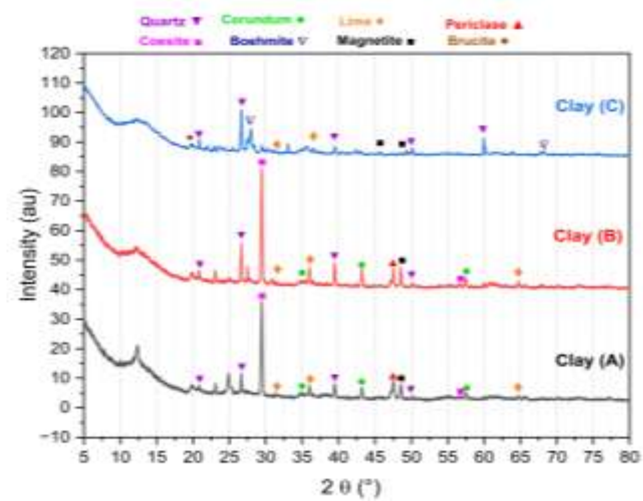


Fig. 4. XRD pattern for different types of clay used in this study show the crystal structure of each materials composition.

6.2 Fabrication of transparent glaze

To optimize the combustion temperature and fluxing ratio, the required analysis is applied to the developed glaze. The data obtained from glaze will analysis in terms of; (1) evaluation of the glaze characteristics, (2) enable technological reconstruction, and (3) compare especially when attached to stylistic and morphological classifications [2]. To better understand the developed glaze, the glazes were characterized microstructurally by visual analysis, X-ray diffraction (XRD), and scanning electron microscopy (SEM).

6.2.1 Visual analysis

Optical method is one of the common techniques that can indicate behavior of glazes and terracotta surface. A visual analysis of the glaze quality of all samples is shown in **Fig.5.** The glaze characteristics were evaluated in terms of transparency, luster, glossiness, and defects. **Table.3** shows the most important characteristics of different glaze samples at different operating conditions.

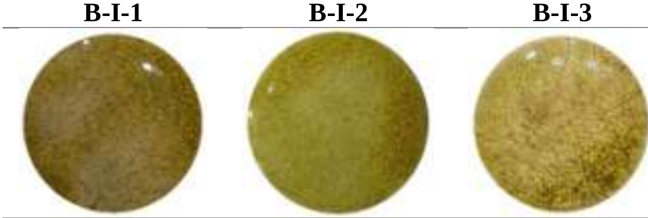
As shown in **Fig. 5** and **Table.3**, strong evidence of transparency and suitability was resulted for the majority of achieved recipes. The best results of all the produced glazes were A-I-2, B-I-2, and C-I-2. This demonstrated that the flux ratio of 70% and the combustion temperature of 1050°C are the best operating conditions. The remaining samples showed a well-known glaze defect such as crazing which occurs due to the differences in the rate of expansion or contraction of the terracotta body and the glaze. There are some other defects such as pin holing defects as found in samples C-I-1 and C-II-2. In addition, there are blistering defects such as those found in A-II-1 and A-III-1. Based on the data obtained from the visual analysis, the best results for clays A, B, and C were determined. Therefore, some other analyses were performed for samples A-I-2, B-I-2, and C-I-2 only.

A-I-1	**A-I-2**	**A-I-3**

A-II-1 | A-II-2 | A-II-3

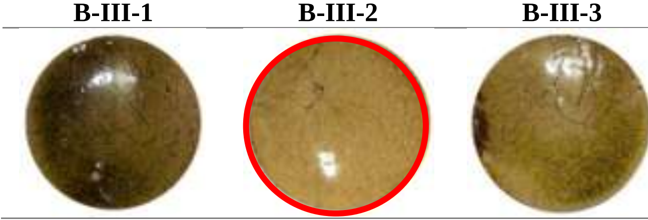
A-III-1 | A-III-2 | A-III-3

B-I-1 | B-I-2 | B-I-3



B-II-1 | B-II-2 | B-II-3

B-III-1 | B-III-2 | B-III-3



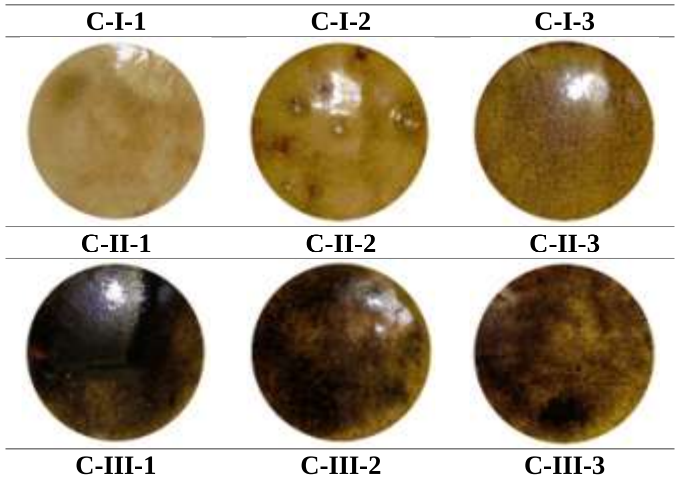
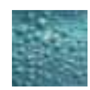


Fig. 5 Digital photographs of glaze samples of different types of clay.

Table 3. Visual analysis glaze characteristics of different samples.

Test Code	Transparency				Glossy		Defects			
	Transparent			Opaque	Glossy	Matt	 Crazing	 Crawling	 Pin Holing	 Blistering
	L	M	H							
A-I-1			√		√		√			
A-I-2			√		√		√			
A-I-3			√		√					
A-II-1			√		√		√			√
A-II-2			√		√		√			
A-II-3		√			√		√			
A-III-1		√			√		√			√
A-III-2			√		√		√			
A-III-3		√			√		√			
B-I-1			√		√		√			
B-I-2			√		√		√			
B-I-3			√		√		√			

B-II-1			√		√	√	
B-II-2			√		√	√	
B-II-3			√		√	√	
B-III-1			√		√	√	
B-III-2		√			√	√	
B-III-3		√			√	√	
C-I-1		√			√	√	√
C-I-2			√		√		
C-I-3		√			√	√	
C-II-1			√		√		
C-II-2		√			√	√	√
C-II-3	√				√	√	
C-III-1				√	√	√	
C-III-2	√				√	√	
C-III-3	√				√	√	

Transparent glossy glaze, no/minor defects **Transparent glossy glaze, medium defects** **Opaque glossy glaze, many defects**

6.2.2 Physiochemical analysis

The XRF and XRD analysis was carried out on the developed glaze frits A-I-2, B-I-2, and C-I-2. The XRF analysis of prepared samples is given in **Table 4**. The sample analysis indicates the presence of silicon dioxide as a major mineral in all samples with the following percentages of 31.92 wt.%, 30.08 wt.%, and 37.01wt.% for glaze samples (A-I-2), B-I-2, and C-I-2, respectively.

The XRD patterns of samples A-I-2, B-I-2, and C-I-2 are shown in **Fig. 6.** XRD analysis was performed from 5◦ to 80◦ (2θ -scale) at a scan rate of 2.5◦/min. As shown in the figure, all samples have amorphous peaks, indicating that no crystal precipitation occurred in the optimal samples and the glaze was vitreous. These results with the appearance of the glaze, this proved that the non-crystalline precipitation of the glaze layer was the internal cause of the glaze's luster transparency. This finding is consistent with the SEM micrograph indicated by **Figs.7**.

Figure.7 shows SEM images of glaze samples and glaze frits, respectively. The results shown in Figs. 7 and 8 explain the high transparency produced by these glazes, indicating that they contain significantly low volumetric fractions of devitrified crystalline phases. Combined with the optical photograph, XRD and SEM result in **Fig.7**, respectively the transparent ceramic glaze and glaze frits (i.e., A-I-2, B-I-2, and C-I-2) can be successfully prepared by the local clay with a fluxing agent.

Two phenomena can be observed the first is the addition of fluxing agent into the clay will intensification the liquid phase, causing in a molten glaze that compresses the interspaces inside the clay [34]. The second is the presence of clay with Cao lime tends to enhance the adhesion between the dry glaze and the raw body [35].**Table 4.** XRF analysis results of samples A-I-2, B-I-2, and C-I-2.

Glaze samples	Constituents (wt.%)												
	Na_2O	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3	P_2O_5	TiO_2	SO3	K_2O	MnO	SrO	ZnO
A-I-2	22.77	31.92	11.55	19.12	0.97	8.66	0.80	2.21	1.15	1.11	0.09	0.09	0.29
B-I-2	31.28	30.08	6.40	20.26	1.06	7.36	0.48	0.98	0.66	0.95	0.11	0.11	0.08
C-I-2	31.12	37.01	8.87	5.13	1.27	11.47	0.56	1.19	0.96	0.86	0.20	0.07	0.07

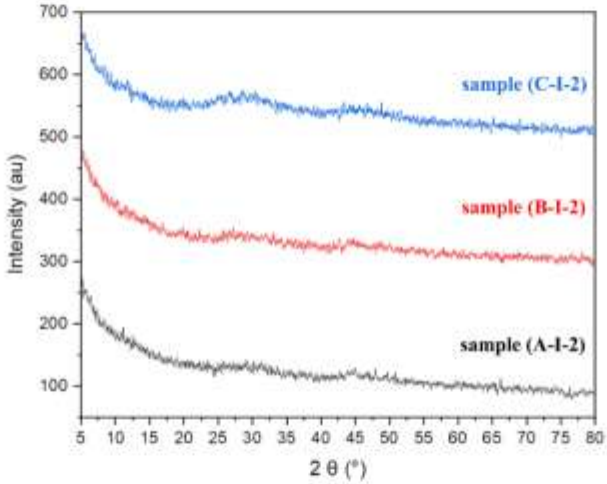
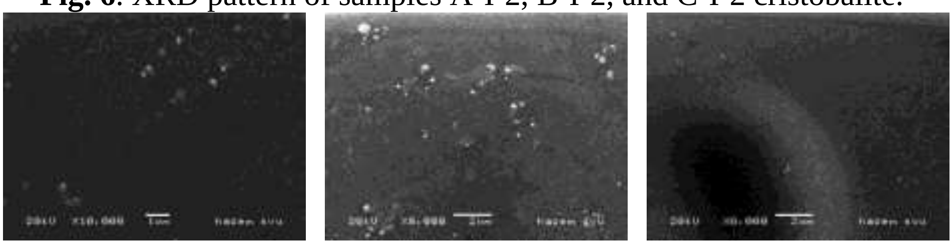
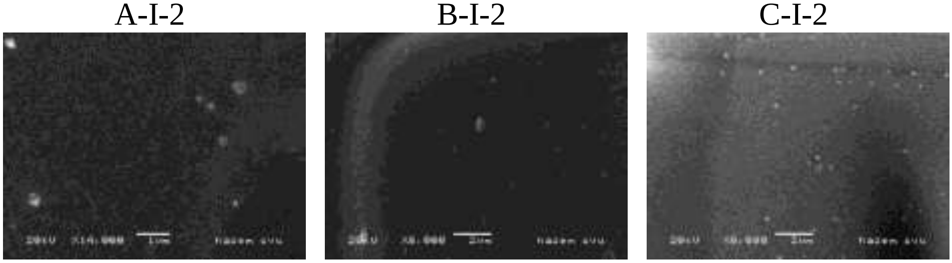


Fig. 6. XRD pattern of samples A-I-2, B-I-2, and C-I-2 cristobalite.



A-I-2 B-I-2 C-I-2



A-I-2 B-I-2 C-I-2

Fig. 7. SEM micrographs of samples A-I-2, B-I-2, and C-I-2., SEM micrographs of sample frits a-I-2, b-I-2, and c-I-2.

7. Conclusion

The development and utilization of raw materials of ceramic involve glaze have great importance in ceramic industry. This process gives ceramics excellent characteristics such as being waterproof, hygienic, beautiful, strong, and having attractive appearance. The resulted transparent ceramic glaze using different types of local clay using only an alkaline fluxing agent. The production process was conducted at different firing temperatures of 1000°C, 1050°C, and 1100°C, using borax as fluxing agents at different ratios of 50%, 60%, and 70%. The development of the glaze process achieves the following characteristics.

- XRD analysis results indicate the presence of many compositions mainly used in transparent ceramic glaze production, especially SiO_2, Al_2O_3, and Na_2O.
- Many experiments were carried out at different firing temperatures and alkaline fluxing agent percentages.
- The best results of transparent glaze were achieved at a firing temperature of 1050°C and fluxing agent ratio of 70% for all used clays.
- The obtained results demonstrated the possibility of developing transparent ceramic glaze using only certain types of clay and alkaline fluxing agent without any other additions.

References

[1] J. Ohimai and E. Okunna, "Developing Medium Range Temperature Glazes Using Locally Sourced Raw Materials," *Tropical Built Environment Journal*, vol. 1, no. 6, 2017.

[2] T. Pradell and J. Molera, "Ceramic technology. How to characterise ceramic glazes," *Archaeological and Anthropological Sciences*, vol. 12, no. 8, p. 189, 2020.

[3] M. Leśniak, W. Jastrzębski, M. Gajek, J. Partyka, D. Dorosz, and M. Sitarz, "The structure of model glasses of the amorphous phase of glass-ceramic glazes from the SiO2Al2O3CaOMgONa2OK2OZnO system," *Journal of Non-Crystalline Solids*, vol. 515, pp. 125-132, 2019.

[4] R. Pina-Zapardiel, A. Esteban-Cubillo, J. Bartolomé, C. Pecharromán, and J. Moya, "High wear resistance white ceramic glaze containing needle like zircon single crystals by the addition of sepiolite n-ZrO2," *Journal of the European Ceramic Society*, vol. 33, no. 15-16, pp. 3379-3385, 2013.

[5] M. Tite, I. Freestone, R. Mason, J. Molera, M. Vendrell- Saz, and N. Wood, "Lead glazes in antiquity—methods of production and reasons for use," *Archaeometry*, vol. 40, no. 2, pp. 241-260, 1998.
[6] M. A. A. Muhamad Nor and N. H. Hazwani Ya'acob, "Development of Decorative Ceramic Glaze from Palm Fiber Ash," *Key Engineering Materials*, vol. 690, pp. 259-263, 2016.
[7] H. Huang, J. Yu, F. Liu, and H. Zeng, "Preparation of A High-Performance Frit Glaze Using High-Potassium Feldspar," in *IOP Conference Series: Earth and Environmental Science*, 2021, vol. 943, no. 1: IOP Publishing, p. 012018.
[8] H. B. Poyraz, N. Erginel, and N. Ay, "The use of pumice (pumicite) in transparent roof tile glaze composition," *Journal of the European Ceramic Society*, vol. 26, no. 4-5, pp. 741-746, 2006.
[9] P. Riello *et al.*, "Nucleation and crystallization behavior of glass-ceramic materials in the Li2O–Al2O3–SiO2 system of interest for their transparency properties," *Journal of non-crystalline solids*, vol. 288, no. 1-3, pp. 127-139, 2001.
[10] R. J. Revelo, A. P. Menegazzo, and E. B. Ferreira, "Cathode-Ray Tube panel glass replaces frit in transparent glazes for ceramic tiles," *Ceramics International*, vol. 44, no. 12, pp. 13790-13796, 2018.
[11] F. G. Melchiades, B. T. Rego, S. M. Higa, H. J. Alves, and A. O. Boschi, "Factors affecting glaze transparency of ceramic tiles manufactured by the single firing technique," *Journal of the European Ceramic Society*, vol. 30, no. 12, pp. 2443-2449, 2010.
[12] R. Eppler, "Use of Scattering Theory to Interpret Optical Data for Enamels," *Journal of the American Ceramic Society*, vol. 54, no. 2, pp. 116-120, 1971.
[13] I. Atkinson, O. C. Mocioiu, and E. M. Anghel, "A study of zircon crystallization, structure, and chemical resistance relationships in ZrO2 containing ceramic glazes," *Boletín de la Sociedad Española de Cerámica y Vidrio*, vol. 61, no. 6, pp. 677-685, 2022.
[14] S. Son and K. Kim, "Effect of TiO2 content on crystallization behavior of CaO–Al2O3–SiO2–ZnO glass-ceramic glaze," *Ceramics International*, vol. 49, no. 9, pp. 13677-13686, 2023.

[15] Y. Long, H. Huang, M. Lv, K. Guan, and C. Peng, "Preparation of transparent glaze enhanced by mullite crystals with branched architecture," *Materials Letters,* vol. 335, p. 133808, 2023.
[16] J. Zheng, K. Xu, H. Wang, W. Sun, J. Sun, and J. Liu, "Effect of bentonite content on the suspension stability of a glaze slurry and final enamel performance," *Ceramics International,* vol. 49, no. 6, pp. 9493-9501, 2023.
[17] A. A. Veshareh, P. Mohammadi, A. Elikaei, M. G. Shahraki, G. Rahmani, and M. Ranjbaran, "Laboratory modeling of glazed tiles inoculated with deteriorative fungi isolated from Masjed-e Jāmé Isfahan and evaluation of their impacts," *International Biodeterioration & Biodegradation,* vol. 178, p. 105559, 2023.
[18] J. Partyka, K. Pasiut, P. Jeleń, J. Michałek, K. Kaczmarczyk, and D. Kozień, "The impact of nano-quartz on the structure of glass-ceramic glazes from the SiO2–Al2O3–CaO–MgO–Na2O–K2O system," *Ceramics International,* vol. 46, no. 15, pp. 23888-23894, 2020.
[19] C. Holé, Z. Ren, F. Wang, J. Zhu, T. Wang, and P. Sciau, "Study of the growth mechanism of ε-Fe2O3 crystals in Chinese sauce glaze replications," *Materials Today Communications,* vol. 33, p. 104329, 2022.
[20] C. Xu, W. Li, X. Lu, W. Zhang, X. Liu, and J. Xu, "Potential fingerprints for the usage of botanic ash in the glaze recipes of the Jizhou tea bowl," *Journal of the European Ceramic Society,* vol. 42, no. 9, pp. 4016-4023, 2022.
[21] T. Hui *et al.*, "Recycling of extracted titanium slag and gold tailings for preparation of self-glazed ceramic foams," *Ceramics International*, vol. 48, no. 16, pp. 23415-23427, 2022.
[22] F. Gol *et al.*, "Evaluation of solid wastes in the manufacture of ceramic tableware glazes," *Ceramics International*, vol. 48, no. 11, pp. 15622-15628, 2022.
[23] P. Liu *et al.*, "Analysis of the influence of iron source and its occurrence state on the color of celadon glaze," *Ceramics International*, vol. 48, no. 13, pp. 18425-18432, 2022.
[24] S. Wang *et al.*, "Anorthite-based transparent glass-ceramic glaze for ceramic tiles: Preparation and crystallization mechanism,"

Journal of the European Ceramic Society, vol. 42, no. 3, pp. 1132-1140, 2022.

[25] J. Hou *et al.*, "The birth of copper-red glaze: Optical property and firing technology of the glaze from Changsha Kiln (8th–9th century)," *Journal of the European Ceramic Society,* vol. 42, no. 3, pp. 1141-1148, 2022.

[26] S. Sun *et al.*, "A zirconium-free glaze system for sanitary ceramics with SiO2-CaCO3-TiO2 composite opacifier containing anatase: Effect of interface combination among SiO2, CaCO3 and TiO2," *Journal of the European Ceramic Society,* vol. 42, no. 5, pp. 2523-2534, 2022.

[27] F. Gol *et al.*, "Reuse of glass waste in the manufacture of ceramic tableware glazes," *Ceramics International,* vol. 47, no. 15, pp. 21061-21068, 2021.

[28] K. Kaczmarczyk, J. Partyka, K. Pasiut, and J. Michałek, "Strontium carbonate in glazes from the SiO2–Al2O3–CaO–MgO–Na2O–K2O system, sintering and surface properties," *Open Ceramics,* vol. 9, p. 100233, 2022.

[29] K. Pasiut, J. Partyka, M. Lesniak, P. Jelen, and Z. Olejniczak, "Raw glass-ceramics glazes from SiO2–Al2O3–CaO–MgO–Na2O–K2O system modified by ZrO2 addition–changes of structure, microstructure and surface properties," *Open Ceramics,* vol. 8, p. 100188, 2021.

[30] S. Sun, H. Ding, W. Ao, Y. Liu, L. Chang, and J. Zhang, "Preparation of a CaCO3-TiO2 composite based opaque glaze: Insight into the mechanism of opacification and glaze yellowing inhibition," *Journal of the European Ceramic Society,* vol. 40, no. 15, pp. 6171-6180, 2020.

[31] L. B. Ayieng'a, A. Wang, X. Lu, Y. Song, and M. Watterson, "Research on Porcelain Material for Product Design and Manufacturing in Kenya: Assessing SiO 2 Al 2 O 3 Content," 2022.

[32] P. Muñoz, V. Letelier, L. Munoz, O. Gencel, M. Sutcu, and M. Vasic, "Assessing technological properties and environmental impact of fired bricks made by partially adding bottom ash from an industrial approach," *Construction and Building Materials,* vol. 396, p. 132338, 2023.

[33] M. Jordán, A. Boix, T. Sanfeliu, and C. De la Fuente, "Firing transformations of cretaceous clays used in the manufacturing of ceramic tiles," *Applied Clay Science,* vol. 14, no. 4, pp. 225-234, 1999.

[34] S. M. Kazmi, S. Abbas, M. A. Saleem, M. J. Munir, and A. Khitab, "Manufacturing of sustainable clay bricks: Utilization of waste sugarcane bagasse and rice husk ashes," *Construction and building materials,* vol. 120, pp. 29-41, 2016.

[35] M. Levy, T. Shibata, and H. Shibata, *Wild Clay: Creating Ceramics and Glazes from Natural and Found Resources*. Bloomsbury Publishing, 2022.