The Peerian Journal
Open Access | Peer Reviewed
Volume 25, December, 2023.
ISSN (E): 2788-0303
Website: www.peerianjournal.com
Email: editor@peerianjournal.com

The Possibility of Producing Maiolica Glass from Local Materials

[1] Mohammed Hamdan Shamkhi Al-Zrgan and [2] Ali Ghadhban Sukkar
[1] Ministry of Education, Najaf Directorate of Education
[2] University of Babylon, College of Fine Arts
mh028842@gmail.com
G.S_ALI76@uobabylon.edu.iq

Abstract. This paper aims to explore the feasibility of producing basic white glass (Maiolica) from local materials and applying it to the surfaces of pottery bodies made from local clay (Al-Mahawil clay in Babil Governorate). The current research consists of five chapters. Chapter one presents the research problem as follows: Is it possible to produce Maiolica glass from local materials? The significance and necessity of this research lie in environmental protection by recycling and reusing accumulated palm frond residues to enhance artistic taste and beauty in pottery, besides achieving economic benefits. The research sets the temporal, spatial, and objective boundaries, defines terms, and introduces the theoretical framework in the second chapter. This framework includes understanding the primary materials of glass and its classifications into transparent and opaque glass. Chapter three is allocated to the research procedures, employing an experimental approach. It involves formulating a mixture of palm frond ash with additives based on a specific ratio and subjecting the mixtures to a set standard. Chapter four presents and discusses the findings, including three models representing the research population, where laboratory tests were conducted to measure surface tension, glass density, and texture. Supporting tests, such as microscopic examination, aimed to identify crystalline formations, phases, and unmelted substances. Chapter five draws conclusions, offers recommendations, lists indexed sources, references, and appendices.
Keywords..

1. Chapter One

1.1. Statement of the Problem

Pottery and ceramics represent one of the oldest inventions of Mesopotamia in the ancient Iraqi civilization. Glass pottery is among the beautiful and intriguing techniques due to their effects on the produced pottery pieces. Pottery has been technically and historically linked to its glass material through the meanings and values that have remained deeply rooted until now. Artisans developed pottery to meet their essential life requirements, and this craft advanced due to the evolution of human thinking and the accumulation of experiences over successive periods. This led artisans to distinguish between the pottery pieces to select what suits their pottery works. Ancient potters also focused on seeking coatings to cover the surfaces of pottery, to seal porosity, prevent

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liquid leakage, strengthen ceramics, and adorn them with different themes of life, society, and religion.

Given the significant association between glassing and scientific and technological advancements, diving into this process is an important scientific step to support the value of contemporary pottery production. Glassing technology represents an essential part of its aesthetic formation. Therefore, the capabilities of potters in handling and adapting materials and showcasing their positive qualities become a means to achieve their ultimate goal of producing ceramic achievements that serve aesthetic, material, and artistic aspects. These capabilities can only evolve through the harmonization between talent and practice. Hence, glassing and pottery techniques diversified to create various techniques based on the type of technology used according to the added compounds and elements in the composition.

Due to the chemical nature of Iraqi pottery, particularly in the provinces of central Euphrates characterized by their red colors, the main problem arises from the lack of pure white clay free from color impurities, especially the presence of iron oxide, for instance. The firing process for these pots produces dark colors like tan, red, and yellow. Therefore, there is a need to coat these potteries with a white lining (Maiolica glass) to later add pigments and coloring oxides to meet glassing requirements. Considering the high prices of white glass, there is a need to use available and cost-effective local materials to produce this type of glass. Moreover, other colors don't appear vibrant unless applied on a white surface. Maiolica ceramics represents one of these techniques in ceramic glassing for what this technique creates as a fundamental base (lining) placed on the ceramic body, serving as the primary nucleus for adding pigments and coloring oxides to enhance the beauty and radiance of the completed ceramic work.

1.2. Significance of Research

The significance of the research is demonstrated in the following aspects:

1. Producing local white-based glass (Maiolica) from readily available and cost-effective materials.
2. Allowing potters to utilize this produced glass in various artistic and aesthetic purposes at low costs, enhancing the creative process.

1.3. Objectives of Research

The research aims to achieve the following:

1. Producing white-based glass (Maiolica) and identifying its specifications.
2. Assessing the suitability of local pottery (Muhawil clay) for this produced glass.
3. Obtaining low-temperature (950-1000-1050 °C) white-based Maiolica glass.

1.4. Limits of Research

- Location: University of Babylon, College of Fine Arts, Department of Visual Arts, Pottery Branch
- Timeframe: (1/4/2023 – 10/10/2023)
- Objective Factors:
- Palm Frond Ash
- Sodium Carbonate Na_2CO_3
- Potassium Feldspar $K_2O.\ Al_2O_3.\ 6SiO_2$
- Alumina AL_2O_3
- Boric Oxide B_2O_3

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- Tin Oxide SnO_2
- Pottery:
- Local Red Pottery
- Tools and Equipment:
- Electric Kiln (30x35x48 cm)
- Electric Scale with Thermocouple Temperature Gauge
- Electric Grinder (Ball Container)
- Crucible for Melting
- Iron Tongs
- Metal Container

1.5. Definitions

1.5.1. Maiolica

It is the process of producing white pottery glass from local Iraqi materials, used as a base lining for pottery pieces, serving as a canvas for adding colorants, providing distinctive artistic and technical qualities (Trembley, 2012: 80).

Procedural Definition of Maiolica Glass

It is the basic white glass prepared by adding up to 50% palm frond ash with other materials, used as a lining for applying colored glass later.

2. Chapter Two: Theoretical Framework and Previous Studies

2.1. Primary Components of Glass

The primary materials constituting glass are divided into three main categories:

1- Acidic Materials.

2- Alkaline Materials.

3- Intermediate Materials (Neutral).

2.1.1. Acidic Materials:

These compounds are the main components of glass, also known as Network Formers, with silica being the most significant, along with Boric Oxide (B_2O_3) (Al-Badri, 2002: 76).

1-1- Silica (SiO_2):

Silica is the most abundant oxide in the earth's crust, representing about 27% of its composition. It is typically found in the form of silicon dioxide (SiO_2) as clay or feldspar (Al-Zamzami, 1996: 148).

Silica exists in both crystalline and non-crystalline forms. Its crystalline structure comprises four oxygen atoms surrounding a silicon atom, creating a tetrahedral molecule (SiO_4). The chemical formula for silica is SiO_2 (Sienko & Plane, 1986: 529-533).

1-2- Boric Oxide (B_2O_3):

Boric Oxide (B_2O_3) is the second most significant oxide forming the glass network. It exhibits multiple reactive and physical properties in ceramic glass. Structurally, B_2O_3 is categorized among the oxides with reactivity (R_2O_3), having the ability to interact with bases and acids. It stabilizes crystallization and bonds between elements similar to alumina (Cooper et al., 1978: 63-64).

Its melting point is relatively low (500°C), making it a potent flux at lower temperatures. However, it is not used alone in glass production due to resulting mechanical and chemical weaknesses; instead, it is added in small proportions (not exceeding 15%) to achieve specific characteristics without compromising the glass's integrity (Lehman, 2002: 88).

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The Boric Compounds:

- Borax: $Na_2O\ 2B_2O\ 10H_2O$
- Boric Oxide: $B_2O_3\ 2H_2O$
- Golemanite: $2CaO\ 3B_2O_3\ 5H_2O$

2.1.2. Alkaline Materials (Network Modifiers):

These materials are added to modify glass specifications and reduce its melting temperature. They comprise alkalis (R_2O) and alkaline earths (RO):

2-1- The Alkalies (R_2O):

These colorless metallic oxides are commonly found in nature and are often soluble in water or combined with silica as feldspar. Their primary significance in glass lies in lowering melting temperatures, increasing glass fluidity, influencing glass expansion coefficients, enhancing hardness and resistance to weathering, improving luster, and facilitating the development of various glass colors (Warren, 1940: 85).

2-2- The Alkaline Earths (RO):

This group includes calcium oxide (CaO), magnesium oxide (MgO), barium oxide (BaO), and zinc oxide (ZnO). While having lower melting points compared to the first group, their specifications vary. However, they are widely available in nature in various compound forms (Alam, 1967: 75).

2.1.3. Intermediate Materials (Amphoterics):

These are intermediate oxides that exhibit dual reactivity. The most important is alumina (Al_2O_3), which is crucial in all types of glass, distinguishing regular glass from ceramic glass (Hamer, 1975: 5-7).

3-1- Alumina (Al_2O_3):

Alumina is a heat and chemically resistant neutral substance that binds acidic and basic compounds in glass, preventing glass components from leaching. Its presence darkens the glass as insoluble crystals disperse within the molten glass. While it's possible to produce glass without using alumina, such glass would have lower melting points, fluidity, and viscosity. Alternatives to alumina include heat-resistant materials like silica and feldspar, which increase viscosity and reduce fluidity (Cooper, 1978: 6).

Alumina also decreases the coefficient of thermal expansion and surface tension. It is present in glass in the form of feldspar, kaolin, or Cornish stone, and it's found in all pottery (Al-Jubouri, 2010: 76).

2.2. Ready-Made Glass (GLAZE FRIT):

This is a new compound differing in properties from the original ingredients. It undergoes prior fusion and reaction of glass compounds within the glass mixture. It includes fusible oxides that have solubility in water, melting with silica to transform into silicates. These oxides are new materials differing from the original components in composition and properties (Riffithes and Reford, 1965: 90).

The process of "fritting" involves melting the glass mixture in a ceramic crucible until the glass becomes liquid. Then, the crucible is removed from the furnace using tongs at the glass's melting temperature. The molten glass is poured into cold water and crushed afterward using a porcelain mortar and an electric grinder for several reasons:

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1. Some oxides in the mixture, such as potassium oxide, boric oxide, and sodium oxide, are water-soluble. Therefore, these oxides would soak into the ceramic body upon application, distorting the ceramic body and leading to inconsistencies in the glass mixture (Doled, 1964: 16).
2. Disposal of toxic elements like lead, antimony, or barium after they react with silica, as well as other impurities.
3. During glass burning, gases like carbon and sulfur are released, causing pinholes on the glass surface. This process ensures homogeneous glass, faster reactions with certain oxides, such as alkaline earths, and shorter maturation times.

Kaolin Bodies:

These are primary bodies formed during weathering processes on feldspar and settled in their formation areas. Due to their larger particle size, they have less plasticity compared to most sedimentary bodies. These bodies have few metallic impurities like iron, which accounts for their white color. Chemically, they closely resemble pure clay mineral formulas (Waseeg, 1989: 72).

($Al_2O_3.2SiO_2.2H_2O$)

(H_2O-%14 ، Al_2O_3-%40 ، SiO_2-%46) (Rhodes, 1975: 19)

Red Clays:

Among the most common types in nature, these clays are widely available. They're characterized by high plasticity (around 29.5%) due to their fine particle size. They're called red clays due to higher iron oxide content, exhibiting various colors like brown, red, gray-green, or yellow-brown (Dickerson, 1989: 25). These clays also contain high levels of sodium oxide, potassium oxide, calcium oxide, magnesium oxide, iron oxide, and titanium oxide. They have a lower melting point, around 1100°C, forming solid masses at approximately 1000°C (Waseeg, 1989: 67). These clays, used extensively by potters, are prepared and cleaned multiple times in water basins to eliminate salts and impurities (Hofsted, 1975: 19).

Darkening in Glass:

Studying glass darkness requires understanding the physical properties of light on the opaque ceramic surface, how light affects and interacts with the body, and the resulting effects. Partially opaque ceramic glass allows a small part of light to pass through while reflecting and scattering the remaining light, causing blurry vision. Fully opaque glass completely blocks light transmission, making it impossible to see through (Bush, 1999: 854).

Regular reflection occurs on smooth surfaces and partially opaque glass, while irregular reflection occurs on fully opaque glass due to its surface roughness. The viewer's eye prefers smoother surfaces as shiny surfaces reflect light directly into the eye, causing discomfort. Various phenomena such as reflection, refraction, diffraction, scattering, interference, polarization, and dispersion affect glass by either blocking or distorting light, resulting in darkness in glass (Alian, 2007: 37).

Moreover, darkness in glass can occur due to increased levels of colored metallic oxides in the clay and its application. Reactions between the glass layer and the clay layer form mullet crystals. Prolonged glass cooling leads to increased crystal growth and darkness. Also, the presence of gases inside the glass layer forming bubbles contributes to surface opacity. Artificially produced materials like lustre coatings, coloring pigments, glassy colored pencils, silk screen prints, chalk prints, and other manufactured substances also contribute to glass darkness. These substances are

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commonly used for decorative purposes to provide clarity and precision (Dickerson, 1974: 133-134).

In addition to what was mentioned above, darkness can form in glass due to an increase in colored metallic oxides in the clay and the application of glass on it. The interactions between the glass layer and the pottery layer form mullite crystals. Lengthening the glass cooling process increases crystal growth and darkness. Presence of gases within the glass layer forming bubbles also causes darkness on the ceramic surface. There are industrially prepared materials that contribute to glass darkness, such as luster coatings, colorants, glassy colored pens, silk-screen printing, chalk pens, decals, and others. These materials often feature darkness in their composition used for decorations, usually to provide clarity and precision (Ali, n.d.: 65).

The ceramicist relies on the Secor rule in glazing to determine the degree of transparency, darkness, and gloss of glass. According to this rule, a ratio of (1/10) produces transparent glass, (1/7.5) produces glass with partial darkness (semi-opaque), and (1/5) produces fully opaque glass (Al-Ani, 1984: 108).

The light-blocking power of a substance, or the degree of dispersion, depends on the refractive index of the dark substance, the color of the dark substance, the shape and smoothness of the particles, the ratio of the dark materials used, and the thickness of the glass layer. The causes of darkness include crystalline darkness, vitreous darkness, and insoluble darkness.

2.3. Previous Studies

The study by Al-Taher in 2002 focused on the production of ash glass and its applications in Iraqi pottery. Its objective was to explore the possibility of using plant roots and stems in producing high-temperature glass maturing at two temperature degrees (1050-1250°C). Fifteen types of plants (wild plants, plant residues, and solid plant branches) were selected for this purpose, and the pottery body used was kaolin clay capable of withstanding high firing temperatures within the boundaries of Babil Province.

Key results included

1- An increase in silica content resulting in increased hardness in ash glass models, while an increase in other oxides led to decreased hardness.
2- High silica, alkaline earths, and iron resulted in excess materials beyond continuous balanced reactions, causing darkness due to the formation of other liquid phases.
3- "The high fusion resulting from the firing method stabilizing temperature levels to a final maturity led to a decrease in viscosity, allowing the glass sufficient time to re-crystallize and form opacity."

The study differed from Al-Taher's in terms of

1- using a single mixture with varying tin oxide ratios,
2- pre-fritting the mixtures before application at 1100°C,
3- employing low-temperature firing (950°C, 1000°C, 1050°C),
4- using local clay, specifically Maheil clay, coated with white glass.

3. Chapter Three: Methodology

3.1. Procedures

The research procedures involved reviewing scientific, laboratory, and applied research methods adopted by the researcher to achieve the research goals in a presentable, analyzable, and discussable format.

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3.2. Approach

The experimental method was used, known for its precision in revealing causal and compositional relationships in scientific research.

3.3. Choosing Mixture

The mixture selection process involved exploratory experiments where intentional selection of mixture components included palm frond ash,

sodium carbonate (Na2CO3), potassium feldspar (K2O.Al2O3.6SiO2), borax (B2O3), alumina (Al2O3), tin oxide (SnO2), local red clays, and pottery powder.

The choice of palm fronds was due to their abundant availability and chemical analysis indicating a good percentage of alumina (Al2O3) and silica, the primary components of ceramic glass.

Table (3-1) illustrates the chemical analysis of palm frond ash (Al-Tahir, 2002: 25).

Oxides	SiO_2	Al_2O_3	Na_2O	K_2O	CaO	MgO	Fe_2O_3
Palm Leaves	63.8	2.4	2.03	4.7	16.7	6.8	3.6

3.4. Burning Palm Fronds and Preparing Ash:

Palm fronds were washed with water before the burning process to eliminate any possible impurities that might have adhered to them. Then, the plants were burnt outdoors by placing them in a metal container. Ensuring the plant was free of any impurities during the burning process, the fronds were burnt without any assisting materials, with the presence of an airflow, and left for a period of twenty-four hours, as shown in Figure (1 A-B), to complete the burning process. After cooling, these materials were collected and sifted through a 60-mesh sieve to obtain ash free from any foreign bodies, ensuring the combustion of all organic materials, uniformity in burning all parts of the ash, and to eliminate the carbon resulting from the initial burning.

To achieve clean burning and remove the resulting carbon, the ash was placed in a clay container specifically prepared for this purpose and burnt inside an electric furnace at a temperature of 700°C, as shown in Figure (2 A-B). The resulting ash was then collected in a dedicated container in preparation for the subsequent steps.

Figure (1 A - B) shows the process of burning palm fronds

Figure (2 A - B) shows the process of carbon disposal

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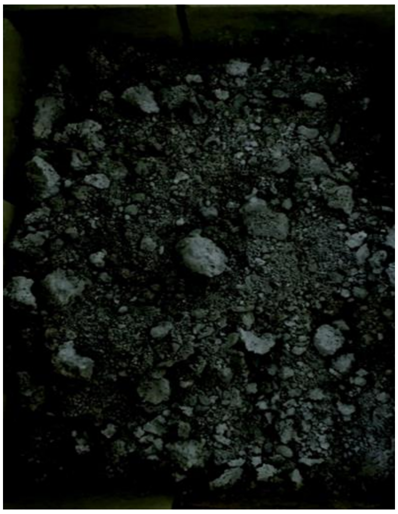

3.5. Choosing the clay applied to the glass:

The researcher selected the clay of Al-Mahawil based on previous research and studies he reviewed, considering all available information about this type of pottery, as it is widely used in the ceramics industry in Babylon.

3.6. Preparation of the models:

The clay was prepared to a pliable consistency by adding a quantity of pottery powder to reduce shrinkage and increase resistance to high temperatures. The mixture was as follows:

Al-Mahawil red clay 80%, Pottery powder 20%.

Table (3-2) illustrates the chemical analysis of Al-Mahawil clay (Al-Hadithi, 1986: 28).

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2CO_3	L.O.I	%
42.75	12.53	5.97	14.35	4.78	1.32	1.9	1.31	14.75	99.66

3.6.1. Modeling:

Once the clay was ready and pliable, it was smoothed onto a wooden board with a thickness of 18 cm, a length of 18 cm, and a width of 1 cm, formed into tiles.

3.6.2. Drying the models:

The models were left covered with a piece of cloth, placed away from any air currents. These pieces were stacked on top of each other and left until completely dry by the second day.

3.6.3. Firing the models:

The models were fired in an electric kiln (Ceramic Kiln at the College of Fine Arts, Babylon University) measuring 30 × 37 × 47 cm at a temperature of 1000°C. All models were placed inside the kiln, ensuring they were free from any signs of warping. Three models were fired according to the firing schedule outlined in Table (3-3), and after 24 hours from disconnecting the electric current from the kiln, the models were removed, as shown in Figure (3 A-B).

Table Number (3-3) Firing Program for Ceramic Models.

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On	Off	Time	Degree
10 sec	60 sec	2: pm till 9: am next day	600 C°
30 sec	30 sec	2 hr	800 C°
Full	Shut down	2 hr	1000 C°
		Additional hour	1000 C°

Figure (3A-B) Firing of Ceramic Models

3.7. Preparing Mixtures of Palm Fronds:

A single mixture was prepared according to the Seker base, determining the percentage ratios of the mixture, which were 100% as the basis for the work. To ensure that the mixtures fit within the Seker base and according to the approved mixing table number (3-4), the percentage ratios must be converted into fractional parts. This is done through the following steps:

Table (3-4) Ratio of Mixture Components.

Ash of palm frond	Ash	% 50
Potassium feldspar	$K_2O.\ Al_2O_3.\ 6SiO_2$	% 30
Boric oxide	B_2O_3	% 12
Carbonated Sodium	Na_2CO_3	% 8

The Law:

1- The percentage ratio of the oxide ÷ its molecular weight.
2- Aggregate the results of the bases together.
3- Divide the results of paragraph 1 by paragraph 2.
4- Calculate the percentage of the materials added from palm frond ash at a ratio of 50% of the prepared main mixture, according to the following law: The molecular weight of the element / The molecular weight of the compound X 50 =

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The percentage ratios are taken from Table (3-1) of the chemical analysis of palm frond ash, and the percentages are calculated as shown in Table (3-5), which shows the distribution of materials within the mixture.

Table (3-5) Percentage and Molecular Weight of the Oxide

No	Oxide	The ratio and molecular weight of the oxide
1.	SiO_2	63.8÷1.06 = 60
2.	Al_2O_3	2.4÷0.02 = 102
3.	Na_2O	2.03÷0.03 = 65 Alkaline
4.	K_2O	4.7÷0.05 = 94Alkaline
5.	CaO	16.7÷0.025 = 65 Alkaline
6.	MgO	6.8÷0.17 = 40 Alkaline
7.	Fe_2O_3	3.6÷0.02 = 160

Sum of the alkaline materials = 0.5 (Na2O + K2O + CaO + MgO)
Values of the weights and molecular parts of the oxides in palm frond ash*

Table (3-6) Values of Weights and Molecular Parts from Palm Frond Ash

No	Oxide	The values of weights and molecular components of palm frond ash
1.	SiO_2	1.06 ÷ 2.12 = 0.5
2.	Al_2O_3	0.02 ÷ 0.04 = 0.5
3.	Na_2O	0.03 ÷ 0.06 = 0.5
4.	K_2O	0.05 ÷ 0.1 = 0.5
5.	CaO	0.025 ÷ 0.5 = 0.5
6.	MgO	0.17 ÷ 0.34 = 0.5
7.	Fe_2O_3	0.02 ÷ 0.04 = 0.5

Table (3-7) Molecular Portion Divided by 50%

No.	Oxide	The value of molecular components	The molecular part is divided by 50%
1.	SiO_2	2.12	1.6
2.	Al_2O_3	0.04	0.02
3.	Na_2O	0.06	0.03
4.	K_2O	0.1	0.05
5.	CaO	0.5	0.25
6.	MgO	0.34	0.17
7.	Fe_2O_3	0.04	0.02

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*It was used 50% of the molecular parts values for the work within the CER base, dividing the above ratios by 50% to be entered in table (3-8) under the field (M.P) according to the proportions of the materials in palm frond ash and based on the CER table.

3.8. Palm Frond Ash Blend

Low Heat Glass
1-----------2.5 Medium Low M
1-------------5 Dark
Low = 2.5 / 0.5 = 5

F Blend Components
Molecular Parts
Molecular Weight (M.w)
M.p X M.w = P.w

Palm Frond Ash = 50%
Potassium Feldspar = 30%
Boric Oxide = 12%
Sodium Carbonate = 8%

Table (3-8) Shows the Proportions of Palm Frond Ash Blend with Additives

%	p.w	m.w	m.p	F	Sio_2	$B2o_3$	Al_2o_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O
0.6	1.68	56	0.03	Na_2O								0.03
0.7	2	40	0.05	K_2O							0.05	
3.9	11.05	65	0.17	CaO					0.25			
8.5	23.5	94	0.25	MgO						0.17		
0.7	2.04	102	0.02	Fe_2O_3				0.02				
0.7	2.04	102	0.02	Al_2O_3			0.05					
34.9	96	60	1.6	SiO_2	1.6							
30	83.4	556	0.15	Feldspar	0.9							
12	33.45	223	0.15	Borax			0.15				0.15	
7.9	21.2	106	0.2	Carbonate		0.3						0.15
												0.2
	276.36				2.5	0.5			1			

3.9. Manufacture of the Crucible:

The crucible manufacturing process involved a mixture of 40% Kaolin as the primary element and 60% Grok. After blending the mixture to a consistent texture, it was shaped into a cylindrical form on an electric wheel. The crucible's interior was coated with a solution consisting of 100% pure Alumina to prevent glass adhesion inside the crucible and minimize glass interaction with the body. It was fired at a temperature of 1300°C to be ready for vitrification and subjected to gas furnace firing.

3.10. Vitrification Process:

The blend was placed in a dedicated crucible and placed in the furnace. It underwent a rapid firing process, reaching a temperature of 1100°C with a one-hour maturing period. After completion of maturation, the researcher extracted the crucible from the furnace at a temperature

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of 1100°C using tongs, as shown in Figure 4. The molten glass was poured into water inside a container (a Fafon bucket) to shatter the glass and prevent the glass crystalline system from reforming, as depicted in Figure 5. After completing the vitrification process, the researcher collected the vitrified glass on one side and placed it in an electric mill crucible (Figure 6) for a continuous six-hour grinding process to achieve uniform grinding and suitable smoothness. Upon completion of the grinding process, the mixture was sifted using a 100-mesh sieve as the final step to obtain a fine and consistent powder. Subsequently, it was placed in special clean boxes labeled with the mixture's name and components, ready for the next step.

Figure (4) Using the Tongs

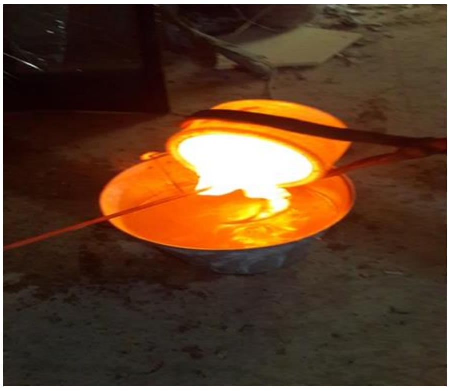

Figure (5) Pouring the Melted Substance into the Container

Figure (6) Using the Grinder to Grind the Mixture

3.11. Applying Mixtures on Ceramic Samples:

The mixture was applied to the surfaces of the samples to study the changes that occur on the ceramic body while maintaining the temperature. A suspension of glass and water was created, adding different proportions of tin oxide in the second and third samples, as outlined in Table (3-9) separately. The application process was carried out using a sprayer, as depicted in Figure (7 A-B).

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Table (3-9) Amount of Added Tin Oxide for Samples

Mixture No.	Fritted Glass	Tin Oxide
1	100	--
2	100	%1
3	100	%2

After the spraying process, the samples are left briefly to dry, avoiding glass separation from the ceramic layer due to water evaporation absorbed by the body. Following this, the samples are placed in the electric furnace.

3.12. Firing Program:

A firing program table was prepared for the samples, as shown in Table (3-9).

Table No. (3-9) Amount of Tin Oxide Added to the Samples

On	**Off**	**Time**	**Degree**
10 sec	60 sec	2 P.M. – 9 A.M. (next day)	600 C
30sec	30 sec	2 Hr	800 C
Full	Shutdown	1.5 Hr	950 C
Soaking Time		1 Hr	

After completing the spraying process, the samples are left for a short period to dry, avoiding the separation of the glass from the ceramic layer due to the evaporation of absorbed water from the body. Then, the samples are placed in the electric furnace.

3.13. Firing Program:

A table was prepared for the firing program specific to the samples as shown in Table (3-10)

Table No. (3-10) Firing Program for the Samples

On	**Off**	**Time**	**Degree**
10 sec	60 sec	2 pm -9am next day	600 C
30 sec	30 sec	2 Hr	800 C
Full	Shutdown	1.5 Hr	950 C
Soaking Time		1 Hr	

3.14. Laboratory Tests:

3.14.1. Calculation of Surface Tension Coefficient:

The surface tension coefficient of the glass was calculated to determine the effect of the materials in the glass composition on the surface tension coefficients based on the surface tension constants table according to Table (3-11) and using the equation below:

(Percentage of Material × Surface Tension Coefficient) = Sum of results for Step (1) for each material + other materials included in each mixture.

Table No. (3-11) Surface Tension Constants for Oxides (Trembley, 2012: 63)

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Firm tension	Surface	Oxide
3.4		SiO_2
6.2		Al_2O_3
1.5		Na_2O
1.2		Pb_3O_4
4.8		CaO
6.6		MgO
0.1		K_2O
0.8		B_2O_3
4.5		FeO
4.5		CuO
4.5		CoO
4.5		NiO
4.5		MnO

Table (3-12) illustrates the percentage ratios involved in the reaction within the components of the mixture.

No	The chemical composition of the ash	Percentage of oxide in the surface tension constant for each oxide.
1.	SiO_2	63.8 × 216.92 = 3.4
2.	Al_2O_3	2.4 × 14.88 = 6.2
3.	Na_2O	2.03 × 3.045 = 1.5
4.	K_2O	4.7 × 0.47 = 0.1
5.	CaO	16.7 X 80.16 = 4.8
6.	MgO	6.8 × 44.88 = 6.6
7.	Fe_2O_3	3.6 × 16.2 = 4.5

Surface Tension Constants Calculation for Samples:
Surface tension constant result for the first sample (376.55).
Sodium Carbonate Ratio Constant 8X 1.5 = 12
Potassium Feldspar Ratio Constant 30 X 2.7 = 81
Boric Oxide Ratio Constant (Al-Bakri, 2018: 66-68) 12X 0.8 = 9.6
Sum of the mixture's result + the above-added materials for the first sample = 479.15
Surface tension constant result for the second sample (376.55).
Sodium Carbonate Ratio Constant 8X 1.5 = 12
Potassium Feldspar Ratio Constant 30 X 2.7 = 81
Boric Oxide Ratio Constant 12X 0.8 = 9.6
Tin Oxide Ratio Constant ( ) 1 X 2.8 = 2.8

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Sum of the mixture's result + the above-added materials for the second sample = 481.95
Surface tension constant result for the third sample (376.55)
Sodium Carbonate Ratio Constant 8X 1.5 = 12
Potassium Feldspar Ratio Constant 30 X 2.7 = 81
Boric Oxide Ratio Constant 12X 0.8 = 9.6
Tin Oxide Ratio Constant (Al-Bakri, 2018: 66-68) 2 X 2.8 = 5.6
Sum of the mixture's result + the above-added materials for the third sample = 484.75
Density Constant Calculation:

Density is significantly important in calculating the refractive index and the value of the refractive index. The density of glass is the result of the density of its constituent oxides. The density of ceramic glass ranges from (8.120 to 2.125 g/cm3). The density was calculated according to Table (3-13), which demonstrates the density constants for oxides using the following equation:

Density = Oxide's Percentage × Oxide's Density Constant / 100 =

Table (3-13) shows the density constant for oxides

Constant Density Factor	Oxide
2.7	SiO_2
3.8	Al_2O_3
2.5	Na_2O
9.1	Pb_3O_4
2.8	$CaCO_3.MgCO_3$
2.5	$K_2O.Al_2O_3.6SIO_2$
1.8	B_2O_3
5.7	FeO
6.4	CuO
5.7	CoO
5.2	Cr_2O_3
6.7	NiO
5.3	MnO

The table number (3-14) illustrates the percentages involved in the reaction within the mixture's components.

No	Oxide	Ratio & Partial Weight of Oxide
1.	SiO_2	63.8*X*1.722 = 100 / 2.7
2.	Al_2O_3	2.4 *X*0.091 =100 / 3.8
3.	Na_2O	2.03*X*0.050 = 100 /2.5
4.	K_2O	4.7*X*0.108 =100 / 2.3
5.	CaO	16.7*X*0.467 =100 / 2.8
6.	MgO	6.8*X*0.238 =100 / 3.5
7.	Fe_2O_3	3.6*X* 0.190 = 100 / 5.3

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Volume 25, December, 2023.
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The density constant result for the first sample is (2.866).
- Sodium carbonate ratio constant: 8X 2.5 / 100 = 0.2
- Potassium feldspar ratio constant: 30 X 2.5 / 100 = 0.75
- Boric oxide ratio constant: 12 X 1.8 / 100 = 0.216

The sum of the first sample result + the above-added substances for the first sample = 4.032
The density constant result for the second sample is (2.866).
- Sodium carbonate ratio constant: 8X 2.5 / 100 = 0.2
- Potassium feldspar ratio constant: 30 X 2.5 / 100 = 0.75
- Boric oxide ratio constant: 12 X 1.8 / 100 = 0.216
- Tin oxide ratio constant: 1 X 6.8 / 100 = 0.068

The sum of the second sample result + the above-added substances for the second sample = 4.1
The density constant result for the third sample is (2.866).
- Sodium carbonate ratio constant: 8X 2.5 / 100 = 0.2
- Potassium feldspar ratio constant: 30 X 2.5 / 100 = 0.75
- Boric oxide ratio constant: 12 X 1.8 / 100 = 0.216
- Tin oxide ratio constant: 2 X 6.8 / 100 = 0.136

The sum of the third sample result + the above-added substances for the third sample = 4.168

3.15. Tests conducted on the samples:

3.15.1. Texture Measurement Test:

A device, represented in figure (8), was used to examine the texture of the research samples to determine the texture grades of the glass layer.
Device Name: PosiTector
Model: KITSTD
Reading: The device reads a range of (0-1000) degrees, ranging from smooth to rough surfaces.

Figure (8): Texture Measurement Device

Figure (9): Digital Microscope

3.15.2. Optical Microscope Examination:

The Digital Microscope (Figure 9) was utilized to examine the research samples to determine the content of the glass layer, specifically looking at:
- Air bubbles
- Insoluble structure crystals

Device Name: Digital Microscope-Color Cmos Sensor

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Model: S04
Magnification Power: (600X)
The examination was conducted in the Ceramics Laboratory, Faculty of Fine Arts, University of Babylon.
I can't directly view or interpret images or diagrams. However, I can describe what the image might show based on your description.

Figure (9): Microscope Examination Device

This image likely represents the appearance of a device used for microscopic examination, possibly showing the structure or components of the Digital Microscope described.

Figure (10): Color Analysis Device (Precise Color Reader)
This image probably depicts the appearance of the Precise Color Reader, used in the Visual Arts Department, Faculty of Fine Arts, University of Babylon, for color analysis, specifically to determine the mathematical representation of color and define its three values (L.A.B).*
Device Name: Precise Color Reader -- Model: Hp-C210

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The description refers to the examination of the Modulus of Rupture using a device for measuring stress and fracture properties, as shown in Figure (11). The measurement unit is likely in N/mm² (Newtons per square millimeter). This examination was conducted in the Materials Engineering Department laboratory at the University of Babylon.

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*The axis (L) represents the vertical scale of shades from black at the base of the object, with a value of zero, to white at the top of the object, with a value of 100. The axis (A), the horizontal axis, represents the positive end as red and the negative end as green. As for the axis (B), the second horizontal axis intersecting the axis (A), its positive end represents yellow, and the negative end represents blue.

I can't view or display images directly. If you need a description or a translation of Figure (12), please describe the content or provide any specific information you'd like to know about it.

"Figure (12 A-B) - Measurement of Radiation Resistance
"Measurement of Porosity (Absorption):

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ISSN (E): 2788-0303
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The porosity was examined by weighing the sample on a sensitive scale after exposing it to water for a period of 15 days. This test was conducted at the College of Materials Engineering, University of Babylon, following the following equation:

$$W = \frac{W - W}{W} \times 100$$

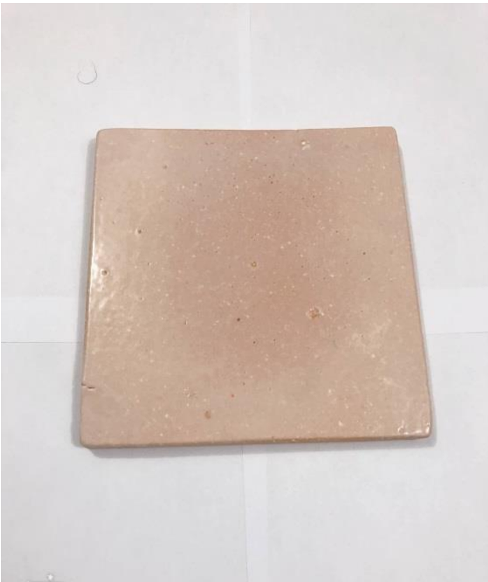
Moist weight GW	Dry weight GW	
33.25	30.35	*1*

$$W = \frac{33.25-30.35}{30.35} \times 100 = 9.5$$

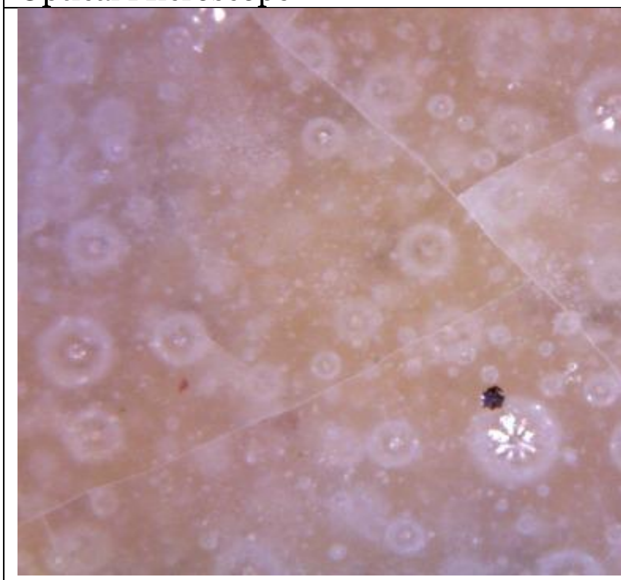
4. Chapter Four: Results and Discussion:

4.1. Results

Table (4-1) shows the results of sample (1) and the tests conducted on it.



Optical Microscope



Sample No.	*1*				
Stress and fracture coefficient	Mpa 18 (N/m²)		sensing	Density (g/cm³)	Surface tension (D/cm³)
Absorption	*9.5*		*20*	*4.32*	*479.15*

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Website: www.peerianjournal.com
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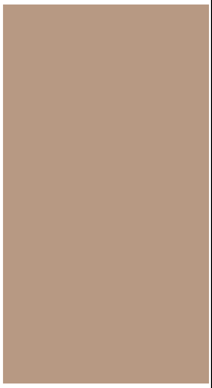
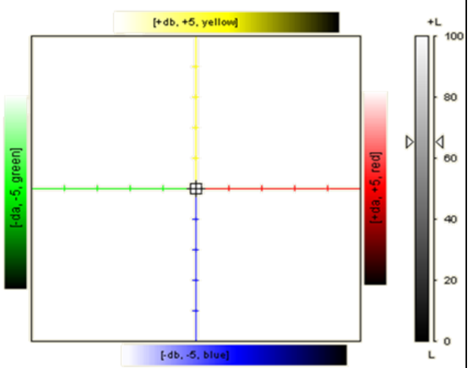
One time test report

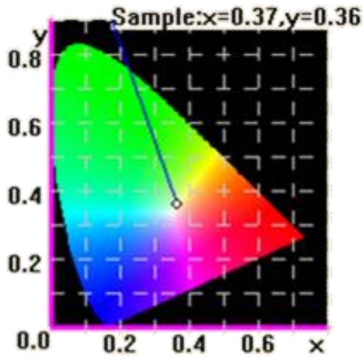
Company: Section:

Test samples: Test instrument: HP-C210 Test condition: D65/SCI/10

Standard Sample						
	L	a	B	L	C	H
	65.59	*7.42*	*15.88*	*65.59*	*17.53*	*64.95*
Test Result						







Conner: Auditing: Date: 2020-1-3

Table (4-2) shows the results of sample (2) and the tests conducted on it.		
		Optical Microscope

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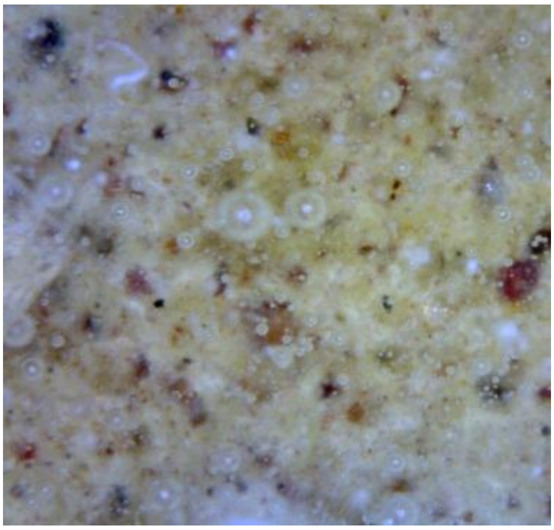
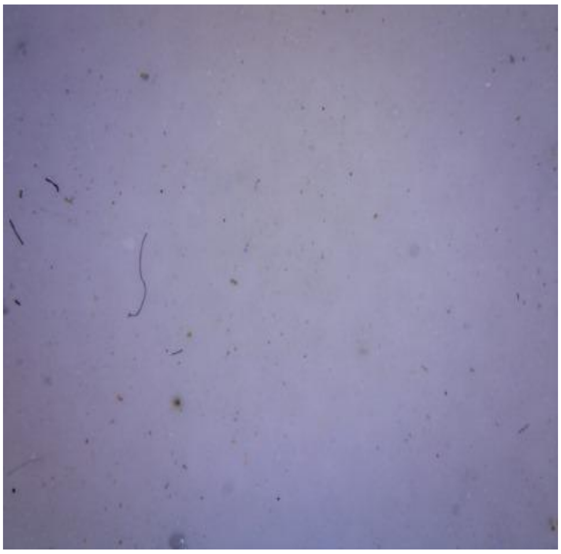


Sample No.	2				
Stress and fracture coefficient	Mpa 19 (N/m²)	Sensing	Density (g/cm)3	Surface tension (d/cm3)	
Absorption	9.5	18	4.1	481.95	

Table (4-3) shows the results of sample (3) and the tests conducted on it.

Optical Microscope



Sample No.	3

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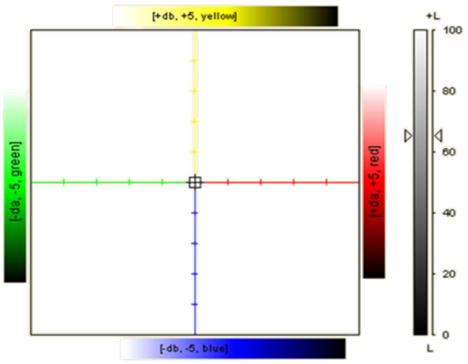
Stress and fracture coefficient	Mpa 17 (N/m^2)		Sensing	Density (g/cm^3)	Surface tension (d/cm^3)
Absorption	*9.5*		*11*	*4.168*	*484.75*

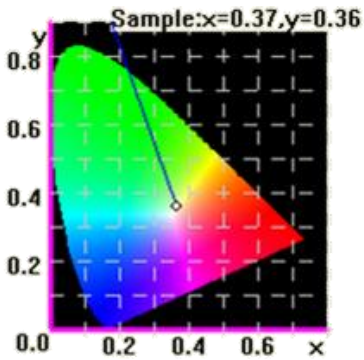
One time test report

Company: Section:

Test samples: Test instrument: HP-C210 D65/SCI/10 Test condition:

Standard Sample						
	L	a	b	L	C	H
	92.56	-2.67	1.80	92.56	2.80	155.95
Test Result						





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4.2. Discussion of Results:

4.2.1. Discussion of Sample Table:

The researcher relied on the "Seger" basis in formulating the glass mixture. Through this, glass components are classified into three primary groups: acids, bases, and neutralizing agents. The majority of ceramic glass mixtures are produced through the equations among these groups. In the current research, a low and medium temperature ceramic glass formula was adopted via the formulation. The components were stabilized to achieve the best results serving the research problem. Ceramic glass consists of a combination and composition of several metallic oxides to produce glass with specific specifications suitable for ceramists' needs and the type of ceramic intended for production. Ceramics exhibit a wide variety in terms of surface types, color, texture, density, and surface tension. The results of these tests vary with the different materials used in the glass mixture as well as the behavior of these materials and their interaction mechanism within the ceramic body concerning the glass layer and the clay body.

The results are also affected by the proportion of main materials composing the glass mixture, other added substances, types of compounds, and oxides. Moreover, certain materials and additives, when added, tend to increase surface tension, density, and texture. In the context of this research, three mixtures of palm leaf ash were used with fixed proportions of sodium carbonate, alumina, potassium feldspar, and boron oxide, with the addition of tin oxide in the second and third models. It's noteworthy that these mixtures were prepared based on the Seger basis, where the results showed improvement in terms of fusibility and enhancement of the opaque glass nature produced concerning strength, external stress resistance, good adhesion to the ceramic layer, and in achieving the objectives of this research in producing opaque glass. This glass could be used as a white lining, low-temperature fusibility, and interaction serving aesthetic, industrial, and technical purposes.

4.2.2. Discussion of Surface Tension Results

The significance of surface tension in pottery glass determines the spread of the glass liquid on the pottery body surface. Retaining this spread after cooling is essential. A decrease in surface tension leads to the fluidity of the glass liquid, while an increase leads to glass clotting, known as withdrawal. Sodium carbonate is notable for balancing the glass structure, reducing errors, increasing the refractive index, reducing glass expansion coefficient and viscosity, reducing surface tension, and enhancing thermal limits for glass maturity. Basic oxides consist of a different range of compounds that fuse in the actual melting process and differ in other properties like surface tension, thermal expansion, viscosity, and fusion temperature. A calculation process was performed to measure the surface tension for glass mixtures based on the surface tension law (Percentage of oxide × Surface tension constant =). Ceramic glass has a surface tension ranging between (150-500 dyne/cm^3). The surface tension constant for the first sample was (479.15), the second sample was (481.95), and the third sample was (484.75).

Comparing the surface tension results of the samples with the globally accepted surface tension values for ceramic glass ranging between (150-500 dyne/cm^3), the current research samples fall within this range. Additionally, the values increase with an increase in the percentage of tin oxide. This is corroborated by the fusion results of the samples, with most exhibiting good fusion at low temperatures, where the sample surfaces are color and reaction homogeneous. Therefore, the surface tension results are in line with the results of this research's samples.

4.2.3. Discussion of Density Results

Density in pottery glass varies based on the type and quantity of materials and oxide compounds added to the glass mixture, whether from the base of the mixture or as added compounds and oxides. The density of the glass is significantly influenced by fusion results, where increased fusibility leads to increased density. Density is also related to the optical phenomena of light, influencing phenomena like refraction and reflection. An increase in density leads to an increase in light reflection ratio, directly proportional to the refractive index. Hence, the glass becomes glossy. Different densities within pottery glass may result in different phases within the glass layer, causing specific opacities, like liquid opacity. Globally, ceramic glass density ranges between (2.125 - 8.120 g/cm^3). Density coefficient can be calculated for glass using the density law (Percentage of oxide × Constant density coefficient / 100 =). Density results in palm leaf ash mixture for the first sample were (4.032), for the second sample (4.1), and for the third sample (4.168). These average values align with the international ceramic glass density standards. These results are homogeneous in terms of fusibility for the ceramic surface and are in line with the current research objectives to produce fundamental white glass.

4.2.4. Discussion of Texture Results

Surface texture was examined using an electronic device (PosiTector), measuring the fluctuations in the surface of the model using millimeters. This device depends on zero readings where it zeroes through an attached glass lens to record a measurement of (0 mm). The examination was performed on the three research models, with readings ranging between (11-18-20) mm, indicating the smoothness of the glass surface. There was a noticeable impact of adding potassium feldspar and sodium carbonate to the glass mixture, increasing their interaction with the presence of reactive oxides like boron oxide, classified as reactive oxides. This interaction results in a smoother surface texture by reducing the gaps within the glass surface of the models. The reaction's magnitude between glass mixture components is a factor affecting texture. Boron oxide was used due to its commonality and usage among potters in various temperature ranges and saturation burn times. To capitalize on this material in artistic ceramics, it was included in the current research mixture.

4.2.5. Discussion of Stress and Porosity Results

Three models were subjected to fracture coefficient testing, yielding results of (17-18-19) Mpa. The total average of these results was (17.6), aligning with ASTM standard specifications for ceramics as depicted in Table (4-4). Regarding porosity (water absorption), it was (9.5), consistent with the physical specifications of global ceramic glass.

4.2.6. Discussion of Thermal and Optical Reflectance Results

The three glazed models were exposed to UV rays in a (Naswietlac-UV-254) device in the Material Engineering Department for (15 days). The results showed color stability and no alteration, indicating resistance to UV rays. Additionally, the samples were exposed to alternating hot and cold water spray for (105 hours), and the result was that the samples did not undergo mechanical or color-related alteration.

5. Chapter Five: Conclusions, Recommendations & Future Suggestions

5.1. Conclusions

1. White foundational glass (Maiolica) can be produced using local materials.
2. A glass surface with good fusion and interaction on ceramic bodies was achieved at low temperatures (950 - 1000 - 1050°C).
3. The resulting glass possesses good specifications through the addition of potassium feldspar as a good melter with sodium carbonate and alumina.
4. The suitability of the Muhayyil clay concerning compatibility with the produced glass.
5. Surface tension results were high, consistent with the fusion results of the samples.
6. Density results were moderate and in line with the fusion of glass mixture components.
7. The use of the fritting process in the current research yielded good results by reducing the temperature, minimizing fusion problems, ensuring glass compatibility, and displaying a good white opacity.
8. The color of the produced models (for the three samples) varied due to the quantity of added tin oxide, the nature of the prepared mixture, the fritting process, and the firing temperature.

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Volume 25, December, 2023.
ISSN (E): 2788-0303
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5.2. Recommendations

1. The researcher recommends grinding all mixture components thoroughly at all preparation stages before firing in the furnace to ensure homogeneity during fusion.
2. Conduct a field survey regarding palm frond ash quantities in all districts to assess the potential for recycling them to produce opaque foundational glass that achieves both economic viability and aesthetic appearance.

5.3. Suggestions

1. Investigate the possibility of lowering the temperature to below (950°C) to produce white glass from local raw materials.
2. Study the addition of other local materials to enhance the appearance of good foundational white glass.
3. Study the feasibility of preparing mixtures for other types of ash to produce foundational white glass.
4. Apply these approved mixtures to the rest of the Iraqi pottery and study the outcomes.

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