Research Inventy: International Journal of Engineering And Science
Vol.15, Issue 9 (September 2025), PP 11-20
Issn (e): 2278-4721, Issn (p):2319-6483, www.researchinventy.com

Development of Low-Temperature Glass Powders for Ceramic Ware Decoration

LamidiYinusa Daniel *[1], Jegede, FloxyImhade and AjayiOlusola Joseph[1]
The Federal Polytechnic, Ado-Ekiti, Ekiti State
**Corresponding Author*

ABSTRACT
This study focused on the development and evaluation of low-melting glass powders for ceramic decoration as a sustainable alternative to conventional high-temperature glazes. Soda–lime and borosilicate glasses were purified, crushed, melted, and fritted at 1200 °C to produce base glass frits. These frits were subsequently milled, sieved, and blended with silica sand, kaolin, and selected colorants to formulate compositions that soften and fuse below 850 °C. The resulting glass powders were prepared as printable slurries using gum arabic and applied to ceramic tiles through screen printing before undergoing final firing at 850 °C. Characterization was carried out using Scanning Electron Microscopy (SEM), Fourier Transform Infrared Spectroscopy (FTIR), and acid resistance testing. The results showed that selected samples, particularly BC, ES, FS, and CS, exhibited excellent melting behavior, strong adhesion, high scratch and acid resistance, and glossy decorative finishes. FTIR spectra confirmed amorphous glass structures dominated by Si–O–Si stretching and depolymerized networks favorable for low-temperature fusibility. SEM micrographs revealed predominantly amorphous morphologies with differences in porosity, particle distribution, and colorant dispersion. Acid resistance testing further confirmed the durability of the coatings, with minimal to moderate attack observed under HCl exposure. Overall, the study demonstrates that low-melting glass systems can provide energy-efficient, cost-effective, and aesthetically versatile solutions for ceramic decoration while maintaining durability and chemical stability.
(keywords: powdered melt, ceramic wares, decoration)

Date of Submission: 01-09-2025 Date of acceptance: 11-09-2025

I. Introduction

The use of glass in ceramic decoration has long played a vital role in enhancing both the aesthetic appeal and the functional performance of ceramic wares (Pradel, 2020). From ancient glazing practices to modern enamel technologies, glass-based decoration has remained central to achieving brilliant surface finishes, improved durability, and resistance to environmental degradation. Traditionally, ceramic decoration relies heavily on high-temperature glazes and overglaze enamels, which are fused to the ceramic surface at firing temperatures often exceeding 1000 °C (Colomban, 2021). While these methods produce long-lasting and chemically stable finishes, they also come with significant drawbacks: high energy consumption, elevated production costs, and technical limitations when applied to delicate or thin ceramic substrates that may deform or crack at such elevated temperatures. In the context of modern industry where sustainability, cost reduction, and process efficiency are increasingly prioritized, these limitations have driven a strong research interest in alternative, low-energy decoration techniques.

Low-melting glass powders represent a promising solution to these challenges. These specially engineered compositions are designed to soften and fuse at firing temperatures below 850 °C, a range significantly lower than conventional ceramic glazes (Ponsot, 2015). By reducing firing temperatures, they minimize energy demand, lower production costs, and extend the range of ceramic bodies that can be decorated, including heat-sensitive or fine-porcelain substrates. Furthermore, low-melting glass systems preserve color vibrancy and allow the use of pigments, metallic oxides, and organic additives that would otherwise degrade at higher temperatures(Boch, 2010) . This makes them particularly suitable for advanced decorative applications, such as intricate surface patterns, metallic lustres, and multi-layered embellishments, thereby expanding the creative possibilities for designers and manufacturers.

Beyond aesthetics, low-melting glass powders also carry functional benefits. Their reduced processing requirements contribute to the development of eco-friendly manufacturing chains, aligning with global trends toward green production technologies. Industrial applications extend beyond household ceramic wares to include architectural tiles, sanitary ceramics, and even technical ceramics, where both surface quality and chemical resistance are essential. To achieve these outcomes, the formulation of low-temperature glass must be carefully tailored. Fluxing agents such as lead-free borates, alkali oxides, and selected modifiers are introduced to lower the softening temperature while maintaining surface gloss, chemical durability, and mechanical stability (Zhang, 2025).

Equally critical to performance is the control of particle size distribution, which affects melting behavior and surface uniformity, as well as the adjustment of thermal expansion to ensure compatibility between the glass layer and ceramic substrate (Fu,2020). Failure to balance these parameters can lead to defects such as crazing, peeling, or loss of adhesion. Therefore, research in this area not only seeks to reduce energy costs but also aims to optimize the microstructural and chemical properties of glass powders for reliable large-scale application.

This research is therefore focused on the development and evaluation of low-temperature glass powders for ceramic ware decoration, with particular emphasis on material formulation, melting behavior, and performance assessment on ceramic substrates. The study aims not only to design compositions that melt effectively at reduced firing temperatures but also to ensure durability, aesthetic quality, and industrial applicability, thereby contributing to advances in ceramic decoration technology.

II. Materials and Methods

Materials

The raw materials used in this study for the development of low-temperature glass powders for ceramic decoration include:

- Glass Sources (Frit): Borosilicate glass and soda–lime glass obtained from the Pilot Plant, Federal Polytechnic, Ado-Ekiti.
- Silica Sand: Collected from Igbokoda, Ondo State.
- Kaolin: Obtained from Okpella, Edo State.
- Metallic Oxides (Colorants): Cobalt oxide, red iron oxide, manganese dioxide, and chromium oxide (obtained fromceramic store).
- Other Additives: Feldspar, calcium oxide, opacifiers, and mixing agents.

Equipment

The equipment used includes kilns, enamel kilns, crucibles, ball mills, pulverizers, sieves, weighing balances, pyrometers, pallets, and screen-printing mesh. Characterization of samples was performed using SEM and FTIR.

Raw Material Preparation

Purification of Glass Sources:

Soda–lime and borosilicate glasses were first thoroughly washed to eliminate dust, grease, and other surface impurities that could interfere with subsequent processing. After cleaning, the samples were carefully dried to prevent moisture-related defects during grinding. The dried glasses were then mechanically reduced in size using a crusher, followed by a high-speed grinder, to obtain smaller, more uniform fragments suitable for further processing and analysis. This step ensured that the glass materials were adequately prepared for melting and compositional modification. The pictorial representations of the prepared samples are presented in Figures 1 to 4.

Figure 1: Sample of borosilicate glass

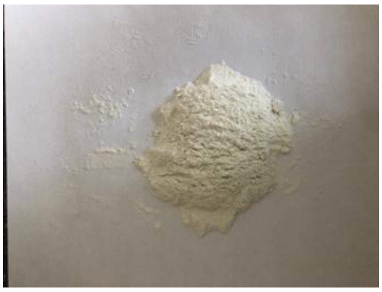

Figure 2: Sample of milled borosilicate glass before milling

Figure 3: Sample of sodalime glass

Figure 4: Sample of milled sodalime glass

Frit Production

As illustrated in Figures 5 to 8, the previously crushed glass samples were subjected to melting in high-temperature refractory crucibles placed inside a kiln. The melting process was carried out at approximately 1200 °C, a temperature sufficient to achieve complete fusion and homogenization of the glass components. Once a uniform molten state was attained, the glass was rapidly quenched by pouring it directly into water. This sudden cooling process, known as fritting, caused the molten glass to shatter into fine, brittle particles, preventing crystallization and ensuring the formation of an amorphous structure.

The resulting frit particles were carefully collected, oven-dried to remove any residual moisture, and then stored in airtight containers to prevent contamination or atmospheric interaction before subsequent processing steps. This preparation of frits served as the foundation for the formulation of low-melting glass powders used in ceramic decoration.

Figure 5: Crucible placed in the Kiln Figure 6: Compositions firede at 1200°C

Figure7: Melted composition Figure 8: Composition poured in water for fritting

Powder Processing and Batch Compositions

The prepared frits, along with silica sand and kaolin, were weighed in accordance with the batch formulations presented in Tables 1–4. Each raw material was carefully measured to ensure accuracy and consistency across the compositions. The mixtures were then subjected to intensive grinding using a ball mill, a process designed to reduce particle size to fine powders. Achieving such fineness is crucial, as it enhances homogeneity during melting, promotes complete reactions between the constituents, and ensures the production of uniform glass powders with desirable physical and chemical properties.

Two distinct sets of formulations were developed: one based on borosilicate frit and the other on soda–lime frit, with controlled variations in the proportions of silica sand and kaolin. This approach allowed for comparative evaluation of how the different base glass systems and additive ratios influence the melting behavior, viscosity, and final performance of the low-melting glass powders.

For standardization, each batch composition was prepared to a total of 100 g, after which 3 g of selected colorants were incorporated into the mixtures. The addition of colorants not only enhanced the decorative potential of the resulting glass but also enabled assessment of pigment compatibility and stability under low-melting conditions. Following weighing and blending, the batches were homogenized further in the ball mill to ensure even distribution of all components before proceeding to the melting and sintering stages.

Table 1: Composition in percentages of the borosilicate frit, silica sand, and kaolin

Sample	Frit	Silica sand	Kaolin
AS	80%	10%	10%
BS	90%	10%	0
CS	95%	2.5%	2.5%
DS	90%	2.5%	7.5%
ES	85%	7.5%	7.5%
FS	90%	7.5%	2.5%

Table 2: Composition in gram (g) of the borosilicate glass frit, silica sand, and kaolin

Sample	Borosilicate frit (g)	Silica sand (g)	Kaolin (g)
AS	80	10	10
BS	90	10	0
CS	95	2.5	2.5
DS	90	2.5	7.5
ES	85	7.5	7.5
FS	90	7.5	2.5

Table 3: Composition in percentages of the soda lime glass frit, silica sand, and kaolin

Sample	Frit %	Silica sand %	Kaolin %
BA	80	10	10
BB	90	10	0
BC	95	2.5	2.5
BD	90	2.5	7.5
BE	85	7.5	7.5
BF	90	7.5	2.5

Table 4: Composition in gram (g) of the soda lime glass frit, silica sand, and kaolin

Samples	Soda lime glass frit (g)	Silica sand (g)	Kaolin (g)
BA	80	10	10
BB	90	10	0
BC	95	2.5	2.5
BD	90	2.5	7.5
BE	85	7.5	7.5
BF	90	7.5	2.5

Glass melt preparationSecond Firing (Fritting):

The homogenized mixtures, already blended with the selected colorants, were subjected to a second firing process in a high-temperature kiln. The firing was carried out at 1200 °C, a temperature sufficiently high to ensure complete melting of the batch materials and full incorporation of the colorants into the glass matrix. This stage is critical, as it determines the chemical homogeneity, stability, and optical properties of the final frit.

Once the mixtures had melted to form a uniform molten glass, they were rapidly quenched inwater to produce glass frits. Quenching is an essential step because it prevents crystallization during cooling, thereby preserving the amorphous structure of the glass and locking in the desired properties. The thermal shock caused by immersion in water also fractured the molten glass into small, irregularly shaped frit particles, making them easier to dry, grind, and reprocess into fine powders for further applications.

The pictorial representations of this process and the resulting frits are shown in Figures 9, 10, and 11. These images highlight the transformation from molten glass to quenched frit particles, marking a key stage in the preparation of low-melting glass powders for ceramic decoration.

Figure 9: Sample in crucible placed in the Kiln for second firing.

Figure 10: Composition poured in water to get the second frit.

Figure 11**:** Samples of the glass frit composition after fritting

Milling and Sieving:

After fritting and quenching, the glass frits were collected, dried, and carefully processed into fine powders to make them suitable for application in ceramic decoration. The frits were first pulverized using a milling machine (Jar mill), which effectively reduced the coarse frit particles into smaller, more uniform sizes. This milling step is crucial because particle size has a direct influence on the melting behavior, smoothness, and adhesion of the glass powders when applied to ceramic substrates.

Following milling, the ground frit was subjected to sieving through standard mesh **sieves** to ensure a consistent and fine particle size distribution. Sieving eliminates oversized particles and aggregates that could cause surface defects, rough textures, or uneven melting during firing. The smooth, fine powders obtained through this process enhance the workability of the glass powders, improve their suspension when applied as slurries, and guarantee a uniform decorative finish on the ceramic surface.

Preparation of Printable Slurry:

The finely milled and sieved glass powders were subsequently mixed with a suitable liquid binder, specifically gum arabic, to produce a stable slurry. Gum arabic was selected due to its excellent binding properties, water solubility, and ability to form smooth suspensions without introducing impurities into the glass

system. When combined with the glass powders, the binder created a homogeneous paste-like mixture with the right rheological properties for controlled application.
The prepared slurry possessed sufficient viscosity and adhesion to enable easy handling and accurate deposition onto the surfaces of pre-glazed ceramic wares. This printable slurry is particularly advantageous because it allows for precise decorative techniques, including screenprinting, hand painting, and brushing, ensuring that intricate patterns and uniform coatings can be achieved.
During the subsequent firing stage, the gum arabic binder burns out cleanly, leaving behind only the glass particles, which then soften, melt, and fuse to the ceramic glaze surface. This results in a smooth, durable, and aesthetically pleasing decoration, while also minimizing defects such as pinholes, cracks, or uneven finishes.

Screen Printing and Final Firing:
A screen-printing mesh technique was employed to apply the prepared glass slurry onto ceramic tiles. The process began with the development of computer-generated designs, which were digitally processed and transferred onto the screen mesh, serving as a stencil for accurate design reproduction. The glass slurry, formulated with gum arabic as a binder, was carefully spread across the screen and pressed through the patterned areas using a squeegee. This ensured precisedeposition of the slurry, enabling sharp edges, fine detailing, and consistent coverage of the decorative motifs on the tile surfaces.
After the screen-printing stage, the coated tiles were allowed to dry to ensure good adhesion and to prevent smudging or distortion of the designs. The decorated tiles were then subjected to a finalfiring in an electric kiln at 850 °C, a temperature carefully chosen to allow the low-melting glass particles to soften and fuse onto the ceramic glaze surface without compromising the structural integrity of the tiles.
This controlled firing process resulted in a smooth, glossy, and well-bonded decorative layer, permanently adhering the design to the ceramic substrate. The relatively low firing temperature not only ensured energy efficiency but also preserved the vibrancy of the colors, prevented pigment degradation, and enhanced the overall durability and aesthetic appeal of the decorated ceramic wares (see Figures 12).

Figure 12: The electric kiln with the samples placed in it for firing.

Characterization of Final Enamel Coatings
To evaluate the quality and performance of the developed low-melting glass coatings, SEM and FTIR were employed for a series of advanced analytical techniques:
Scanning Electron Microscopy (SEM):
SEM is used to examine the surface morphology and microstructural features of the enamel coatings (Schulz, 2020). This technique provided high-resolution images that revealed the texture, particle distribution, porosity, and the degree of homogeneity across the coated surfaces. Through SEM analysis, information on how well the glass powders fused onto the ceramic substrate could be obtained, including the presence of microcracks, voids, or smooth glassy phases that influence durability, gloss, and adhesion.

Fourier Transform Infrared Spectroscopy (FTIR):
FTIR analysis is conducted to identify the functional groups, chemical bonds, and structural characteristics present within the enamel coatings (Baudot, 2010). This technique helped to confirm the incorporation of silica, borates, and other network formers or modifiers in the glass matrix. The spectra also provided insights into the degree of polymerization of the silicate network and the interaction between the enamel coating and added colorants. FTIR results are particularly useful for correlating the composition with observed physical properties such as chemical durability, thermal stability, and color retention.

III. Results and Discusion

After applying the prepared glass melts onto the ceramic substrates and firing them at 850 °C in an electric kiln, the samples were carefully removed and subjected to visual inspection. This assessment focused on evaluating the flow behavior of the melt, its degree of fusion, and the overall compatibility of the glass layer with the ceramic body. Among all the prepared samples, BC, ES, FS, and CS demonstrated the most desirable qualities, including smooth melting, excellent adhesion, high scratch resistance, strong acid resistance, and surface brilliance, making them the most promising candidates for ceramic decoration.

FTIR result of the glass melt

To complement the visual and physical assessments, Figures 13–16 present the FTIR spectra of samples BC, ES, FS, and CS, which provide further insight into their molecular structures and chemical bonding characteristics. These results help in understanding the structural integrity and functional properties of the developed low-melting glass coatings.

From the result, the FTIR spectra of all samples confirmed the amorphous glass structure, dominated by Si–O–Si stretching and bending vibrations. The presence of a non-bridging oxygen (NBO) shoulder around 900–980 cm^{-1} indicated network depolymerization, which supports low-temperature melting and good fusibility. Borosilicate glass (BC) showed additional BO_3/BO_4 bands, highlighting the fluxing role of B_2O_3 in lowering softening temperature. Colourant-doped samples (FS and CS) displayed weak metal–oxygen features (e.g., Fe–O, Cr–O, Co–O) without crystalline peaks, confirming stable incorporation of colorants while retaining glassy character. Minimal OH/CO_3 bands further suggest thermal stability and low risk of surface defects during firing.

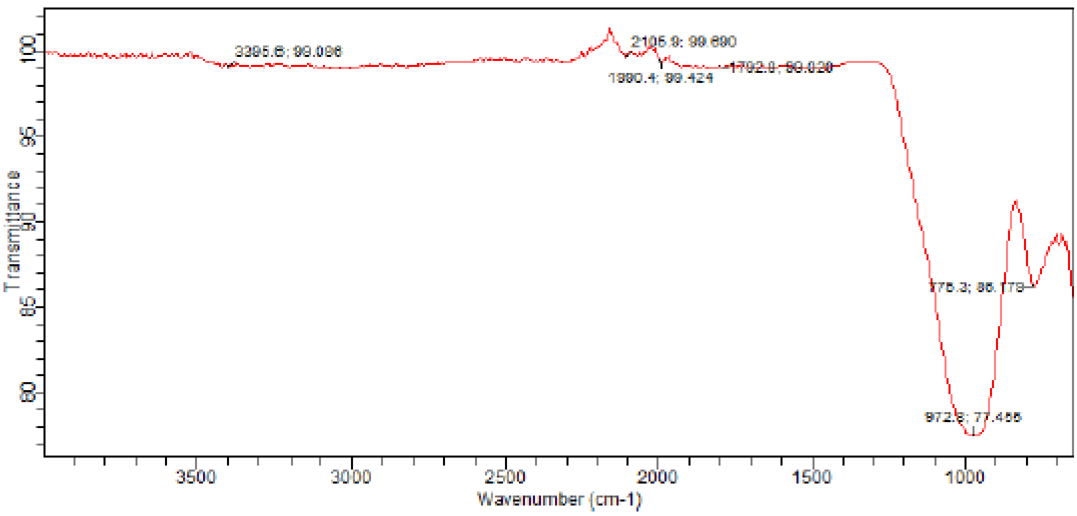

Figure 13: FTIR Result of BC

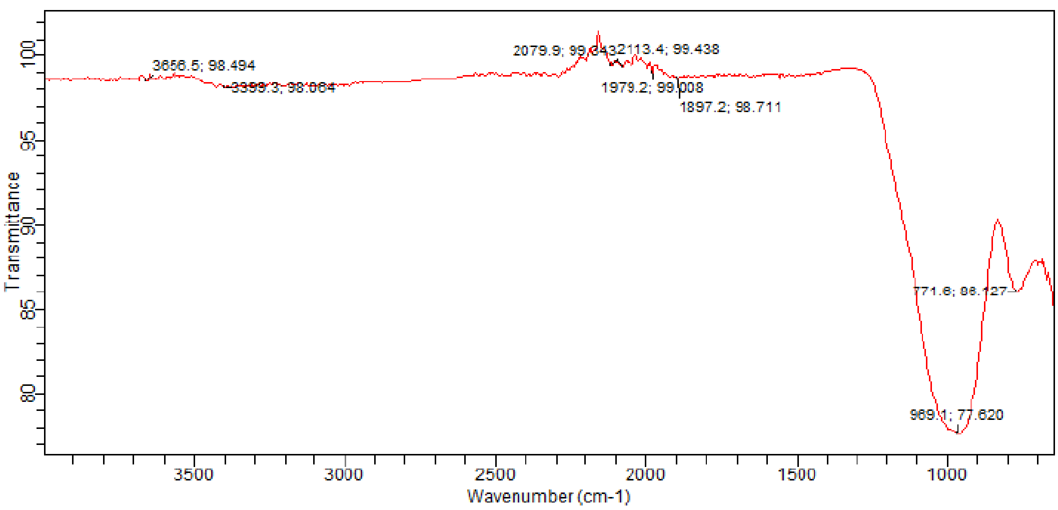

Figure 14: FTIR Result of ES

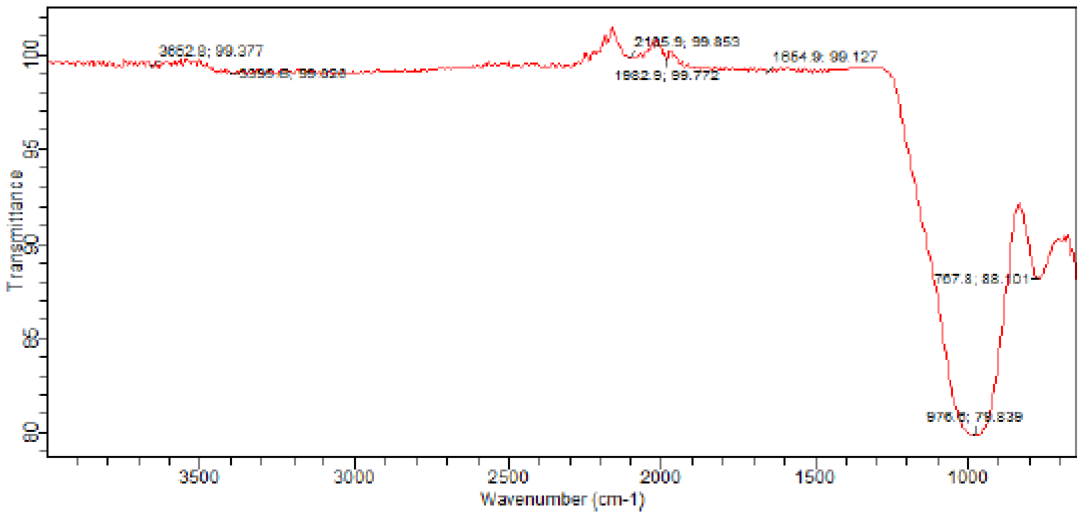

Figure 15: FTIR Result of FS

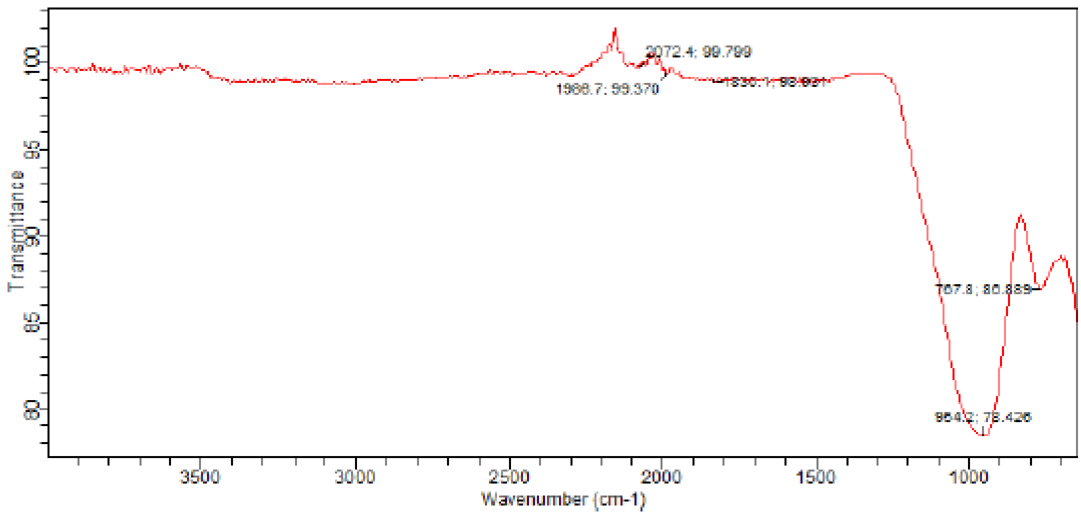

Figure 16: FTIR Result of CS

Result of the decorated ceramic wares after firing

Figure 17 presents the photographs of the decorated ceramic wares produced using the developed low-melting glass powders, showcasing their visual appeal, surface finish, and overall decorative effect. These images highlight how effectively the glass melts fused with the ceramic substrates, producing glossy, smooth, and aesthetically pleasing surfaces suitable for functional and decorative applications.

In addition to the visual evaluation, the acid resistance of the enamel coatings was assessed to determine their durability under chemical exposure. The results of the test, presented in Table 5, show that the samples exhibited good resistance to acid attack, with only moderate surface changes observed after exposure. This indicates that the developed glass coatings possess sufficient chemical stability for practical use, ensuring that they can withstand everyday conditions such as contact with acidic food substances or cleaning agents without significant degradation.

Figure 17: Different samples gotten from the second firing

Table 5: Acid resistance test result of the samples

Sample	Test	Reagnt $ Concentratio	Time	Visual rating	Gloss %
BC	spot	Hcl 5M	3hrs	No attack	Clear
ES	Spot	Hcl 5M	3hrs	No attack	Slight attack
FS	Spot	Hcl 5M	3hrs	No attack	Slight attack
CS	Spot	Hcl 5M	3hrs	No attack	Clear

SEM result of the glass melt

Figure 18 to 21 presents the SEM result of the BC, ES, FS and CS, from the result, the SEM analysis of the glass samples (BS, CS, ES, FS) revealed mainly amorphous glassy structures with differences in particle packing, porosity, and colourant distribution. BS showed a smooth, homogeneous matrix with low porosity, indicating good low-temperature flow. C5 displayed finer particles and dense packing, favoring rapid melting but with some risk of crystallization. ES contained more porosity and coarser particles, which may cause pinholes unless further milling is applied. FS confirmed the presence of metal-oxide colourants; uniform dispersion ensures consistent colour, while clustering may lead to defects. Overall, the SEM results support the suitability of these compositions for low-temperature glass, provided processing is optimized to reduce porosity and improve particle dispersion.

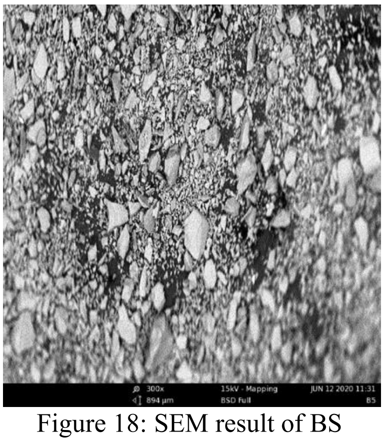

Figure 18: SEM result of BS

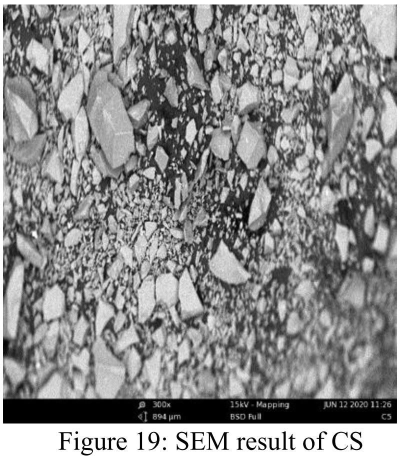

Figure 19: SEM result of CS

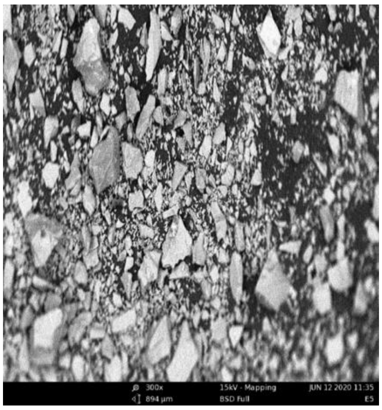

Figure 20: SEM result of ES

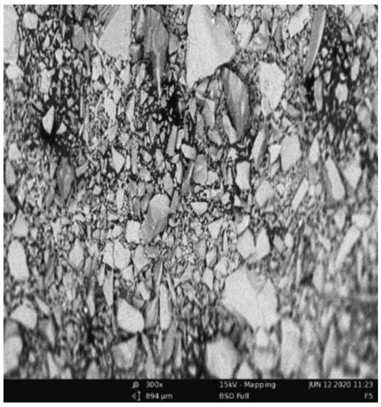

Figure 21: SEM result FS

IV. Conclusion

The research successfully established the feasibility of developing low-melting glass powders for ceramic decoration using soda–lime and borosilicate glass systems. By lowering the firing temperature to 850 °C, the process achieved significant energy savings compared to traditional high-temperature glazing while maintaining desirable decorative and functional qualities. Among the tested samples, compositions BC, ES, FS, and CS stood out for their superior performance in terms of melt flow, surface brilliance, scratch resistance, and acid durability. FTIR analysis confirmed stable amorphous networks capable of incorporating metallic oxides without crystallization, while SEM images highlighted the importance of particle dispersion and porosity control in achieving uniform coatings. The acid resistance results further validated the suitability of the coatings for practical applications, indicating their resilience against common acidic environments. This study therefore demonstrates that low-temperature glass powders can meet industrial needs for sustainable, cost-effective, and high-quality ceramic decoration.

V. Recommendation

Beyond decorative ceramics, the developed low-melting glass powders should be tested for architectural tiles, sanitary wares, and technical ceramics to explore wider industrial applicability.The use of recycled glass and eco-friendly additives should be further integrated to maximize environmental benefits and align with global green manufacturing tren

REFERENCE

[1]. Baudot, C., Tan, C. M., & Kong, J. C. (2010). FTIR spectroscopy as a tool for nano-material characterization. Infrared Physics & Technology, 53(6), 434-438.

[2]. Boch, P., & Ni, J. C. (Eds.). (2010). Ceramic materials: Processes, properties, and applications (Vol. 98). John Wiley & Sons.

[3]. Colomban, P. (2021). Glazes and enamels. Encyclopedia of Glass Science, Technology, History, and Culture, 2, 1309-1325.

[4]. Fu, L., Engqvist, H., & Xia, W. (2020). Glass–ceramics in dentistry: A review. Materials, 13(5), 1049.

[5]. Ponsot, I. N. E. S., & MARIE, M. M. (2015). Glasses and glass-ceramic components from inorganic waste and novel processing.

[6]. Pradell, T., &Molera, J. (2020). Ceramic technology. How to characterise ceramic glazes. Archaeological and Anthropological Sciences, 12(8), 189.

[7]. Schulz, B., Sandmann, D., &Gilbricht, S. (2020). SEM-based automated mineralogy and its application in geo-and material sciences. Minerals, 10(11), 1004.

[8]. Zhang, Z., Liang, L., Zhang, L., Wang, Z., Xi, J., Chen, J., ...& Ning, G. (2025). A Review on the Impact of Additives in Novel Glass Materials. Journal of Sustainable Metallurgy, 1-25.