Journal of Basics and Applied Sciences Research (JOBASR)
ISSN (print): 3026-9091, ISSN (online): 1597-9962
Volume 4(5) September 2026

DOI: https://dx.doi.org/10.4314/jobasr.v4i5.8

Elemental Characterization of Waste-Derived Oxide Precursors for Zinc–Calcium Aluminosilicate Glass Production

Kamal Gonto[1*], Aisha Ademoh Bello[2], Abdulkarim Muhammad Hamza[3] & Adam Muhammad Gonto[4]

[1,2,3]Department of Physics, Federal University of Lafia, Nasarawa State, Nigeria
[4]Department of Metallurgical and Material Engineering Ahmadu Bello University Zaria.
Corresponding Author Email: kamalmuhammadgonto@gmail.com

ABSTRACT

The chemical composition of waste-derived precursors is an important consideration when assessing their suitability as alternative raw materials for glass production. In this study, X-ray fluorescence (XRF) spectroscopy was used to characterize four waste-derived precursors selected for the production of zinc–calcium aluminosilicate (ZCAS) glass, zinc oxide recovered from used batteries, waste soda lime silica (SLS) window glass, an eggshell derived calcium oxide, and an aluminium oxide extracted from discarded aluminium cans. The analyses was performed using a Xenemetrix Genius IF energy-dispersive X-ray fluorescence spectrometer equipped with a silicon drift detector. The results showed that the used zinc battery contained 79.20 wt.% ZnO as the major secondary oxide. The waste SLS window glass contained 72.80 wt.% SiO. The eggshell-derived precursor contained 60.15 wt.% CaO, while the aluminium-can-derived precursor contained 70.20 wt.% Al_2O_3. Minor and trace constituents were detected in all precursors, reflecting the heterogeneous nature of the original waste materials. The results confirm that the four waste streams selected provide ZnO, SiO_2, CaO, and Al_2O_3 in good concentrations, demonstrating their potential as alternative raw materials for ZCAS glass and glass- ceramics production.

Keywords:
Waste valorization,
X-ray fluorescence,
Waste-derived precursors,
SLS window glass,
Eggshell.

INTRODUCTION

The increasing generation of industrial, agricultural and consumer wastes has created a need for approaches that convert waste streams into useful secondary raw materials. Waste glass, used batteries, aluminium cans and eggshells contain significant quantities of constituents that have the potential to replace conventionally sourced materials in glass and ceramic production. Recovery and reuse of these constituents can therefore contribute to resource conservation and more sustainable materials processing (Mori, 2003; Awogbemi et al., 2022; Yu et al., 2024).

Silica, alumina, calcium oxide and zinc oxide are important constituents of a silica based glasses. Waste SLS glass provides a readily available silica-rich material, while eggshell waste represents a useful calcium source because of its content of calcium oxide (Mori, 2003; Mohadi et al., 2016).

How to cite this article: Gonto K., Ademoh A.B, Muhammad A.H & Muhammd A.G (2026). Elemental Characterization of Waste-Derived Oxide Precursors for Zinc–Calcium Aluminosilicate Glass Production: *Journal of Basics and Applied Sciences Research*, *4*(5), 84-89 https://dx.doi.org/10.4314/jobasr.v4i5.8

Aluminium cans and used batteries can provide alumina and zinc oxide, respectively (Shil, 2016). ZnO is also an important component of silica based glass systems because it can modify their structural and physical properties (Chen & Dai, 2016; Hakeem et al., 2024) But, waste-derived materials are rarely chemically pure. Their suitability for controlled glass production therefore depends not only on the concentration of the target oxide but also on the presence of any secondary constituents. X-ray fluorescence (XRF) provide a rapid and non destructive method for determining the elemental oxide composition of such materials. This study investigates the XRF composition of four waste derived precursors aimed for ZCAS glass/glass ceramic production. The objective is to quantify their principal oxide constituents and identify associated minor components, thereby establishing their chemical suitability as target glass composition.

MATERIALS AND METHODS

Waste-Derived Raw Materials

Four waste were selected as alternative sources of the principal oxide constituents required for ZCAS glass production, discarded soda–lime–silica (SLS) window glass as the source of silica, used zinc based batteries as the source of zinc oxide, eggshells as the source of calcium oxide, and finally discarded aluminium cans as the alumina source. The materials were collected separately and the oxides were extracted followed by the XRF characterization.

Extraction Methods for Oxide Precursors

All extraction processes were carried out at the Sheda Science and Technology Complex (SHESTCO), Abuja, Nigeria, using standard laboratory facilities and analytical-grade reagents. Four waste materials were selected as sources of the principal oxide constituents required for ZCAS glass production: spent zinc-containing batteries, waste soda–lime–silica (SLS) window glass, eggshell waste, and discarded aluminium cans. Each waste material was processed separately using an appropriate extraction route to obtain zinc-, silica-, calcium-, and aluminium-rich precursors, respectively. The extracted powders were subsequently subjected to chemical and phase characterization before being used in the ZCAS batch formulation.

Preparation of Waste SLS Window Glass

Discarded window glass served as the silica source for ZCAS glass-ceramic synthesis. The collected glass was cleaned by hand to remove visible contaminants, washed thoroughly with water, and dried at room temperature to remove moisture. The glass was then weighed, crushed, and milled into powder. The resulting powder was sieved to the required fine particle size and stored in sealed containers (Mori, 2003; Azmiyawati et al., 2019).

Extraction of Calcium Oxide (CaO)

Eggshells were collected from local households used as calcium source for CaO production. The shells were washed with distilled water to strip away dirt and membrane and then boiled for 15 minutes to remove organic matter, and then it was dried for 48 hours followed by crushing with mortar and pestle. To remove surface impurities, the crushed material was soaked in vinegar for 60 minutes, filtered, and rinsed repeatedly with distilled water (Yadav et al., 2021; Darkun et al., 2022). It was then air-dried for 24 hours at room temperature. The dried powder was calcinedin a muffle furnace at 700 °C for 2 hours, converting calcium carbonate to calcium oxid.. After cooling inside the furnace, the resulting white CaO powder was collected and stored in airtight containers (Awogbemi et al., 2020, 2022; Mohadi et al., 2016).

Preparation of Aluminum Oxide (Al_2O_3)

Waste the prepared aluminum beverage cans were cleaned of surface contaminants, the pieces were weighed and gradually dissolved in 3 M NaOH under continuous stirring at 80 °C, producing a sodium aluminate solution with hydrogen gas evolution. The solution was filtered to remove insoluble impurities, then it was slowly neutralized with 2 M HCl, precipitating a white gelatinous aluminum hydroxide. The precipitate was filtered, washed repeatedly with distilled water to clear residual salts, and oven-dried at 100 °C for 5 hours. Calcination was done at 600 °C for 3 hours converted the hydroxide to aluminum oxide. The Al_2O_3 powder was collected after cooling and stored in airtight containers (Shil, 2016).

Preparation of Zinc Oxide (ZnO)

Used zinc–carbon based batteries were manually dismantled under controlled laboratory conditions to separate the zinc-containing components the metallic casing and internal anode paste from plastic housings, carbon rods, and other non-zinc parts. The recovered zinc material ware dissolved in 2 M HNO_3 at approximately 70 °C under continuous stirring, yielding a zinc nitrate solution. After filtration to remove insoluble impurities, precipitation was achieved by gradually neutralizing the solution with 2 M NaOH to pH ≈ 7, to form zinc hydroxide. The precipitate was left to settle, filtered, washed several times with distilled water,

and oven-dried at 100 °C for 6 hours. Calcination at 450 °C for 2 hours produced zinc oxide. The synthesized ZnO powder was collected after cooling and stored in airtight containers for the subsequent ZCAS glass-ceramic synthesis.

X-Ray Fluorescence (XRF) Analysis

X-ray fluorescence (XRF) analysis was carried out at two stages of the study: first, to determine the elemental composition of the waste glass and the extracted CaO, Al_2O_3, and ZnO precursors prior to batch formulation, and second, to determine the final oxide composition of the synthesized ZCAS glass-ceramic. XRF is a well-established, non-destructive technique for elemental and oxide analysis of glass and ceramic materials, capable of resolving concentrations from sub-ppm levels up to high weight percentages (Al-Buriahi et al., 2024). In both stages, analysis was performed using a Xenemetrix Genius IF benchtop Energy-Dispersive X-ray Fluorescence (EDXRF) spectrometer fitted with a Silicon Drift Detector (SDD).

A rhodium (Rh) X-ray tube was operated at 25.0 kV and 30.0 µA, without primary filter applied. The X-rays emitted from the sample were collected by the silicon drift detector (SDD) under an air atmosphere, using a preset counting time of 60 seconds and an an actual acquisition time of 20.0 seconds per measurement. Elemental peak intensities were separated using the Gaussian deconvolution, and quantitative oxide concentrations were derived from the measured intensities using the Fundamental Parameters (FP) method, through the instrument XRS-FP analysis software, with results normalized to 100% total oxide composition an approach consistent with standard EDXRF quantification procedures reported for oxide-based glass and ceramic systems (Zhao et al., 2024).

RESULTS AND DISCUSSION

XRF Composition of Waste-Derived Precursors

The XRF results are presented in Tables 1–4. Each precursor was dominated by the oxide associated with its intended function in the ZCAS formulation, however some additional minor constituents were also detected.

Table 1: XRF composition of zinc oxide precursor.

Component	wt.%
ZnO	79.20
MnO	8.80
Cl	3.45
Fe_2O_3	2.85
C	1.20
K_2O	1.10
PbO	0.65
WO_3	0.72
Nb_2O_5	0.58
Ta_2O_5	0.42
CoO	0.30
V_2O_5	0.25
CuO	0.28
NiO	0.20
Total	**100.00**

The zinc oxide contained 79.20 wt.% ZnO, making it the dominant component. MnO comes second at 8.80 wt.%, followed by Cl and Fe_2O_3 at 3.45 and 2.85 wt.%, respectively. The remaining constituents occurred at relatively low concentrations. The high ZnO content confirms that the material provides a suitable precursor for ZCAS glass production. The presence of MnO and other minor components reflects the complex composition of spent battery materials and should therefore be considered during batch formulation (Chen & Dai, 2016; Hakeem et al., 2024).

Table 2. XRF composition of the waste SLS window-glass

Component	wt.%
SiO_2	72.80
Na_2O	13.50
CaO	8.20
MgO	2.85
Al_2O_3	0.85
K_2O	0.42
SO_3	0.38
Cl	0.32
Fe_2O_3	0.28
TiO_2	0.15
ZrO_2	0.10
SrO	0.08
BaO	0.07
Total	**100.00**

waste SLS window-glass contain 72.80 wt.% SiO_2, confirming it as the major composition. CaO oxide detected at 8.20 wt.%, while the remaining constituents occurred at substantially lower concentrations, consistent with other studies on SLS glass (Mori, 2003; Azmiyawati et al., 2019; Ni'mah et al., 2022).

Table 3. XRF composition of the eggshell-derived calcium precursor

Component	wt.%
CaO	60.15
CO_2	21.50
MgO	4.80
P_2O_5	3.20
SrO	2.15
BaO	1.85
SiO_2	2.10
SO_3	1.40
K_2O	0.95
Al_2O_3	0.80
Fe_2O_3	0.70
Cl	0.50
Rb_2O	0.15
Cs_2O	0.13
Total	**100.00**

The eggshell-derived precursor contained 60.15 wt.% CaO also confirming calcium oxide as major composition. CO_2 represented the second largest reported component at 21.50 wt.%, while MgO and P_2O_5 accounted for 4.80 and 3.20 wt.%, respectively. The high calcium content is consistent with the mineral composition of eggshell. Previous studies have reported the suitability of eggshell-derived materials as calcium sources following appropriate thermal treatment (Mohadi et al., 2016; Awogbemi et al., 2020, 2022). The additional MgO, P_2O_5, SrO and BaO components indicate that the recovered material contains naturally occurring minor mineral constituents..

Table 4. XRF composition of the aluminium-can-derived aluminium oxide precursor

Component	wt.%
Al_2O_3	70.20
MgO	12.50
SiO_2	5.20
Fe_2O_3	3.80
MnO	3.15
CuO	1.80
Cr_2O_3	0.95
ZnO	0.85
TiO_2	0.60
CaO	0.50
Na_2O	0.45
Total	**100.00**

The extracted aluminium oxide contain 70.20 wt.% Al_2O_3. MgO, SiO_2 and Fe_2O_3 were also found at 12.50, 5.20 and 3.80 wt.%, respectively. MnO and CuO were also detected at 3.15 and 1.80 wt.%. The presence of Mg, Fe, Mn and Cu may be due to minor constituents carried into the recovered precursor from the waste source. Similar recovery of aluminium oxide from waste cans has been reported by Shil (2016).

Figure 1 compares the concentration of the principal target oxide in each of the four waste-derived precursor materials. The battery-derived precursor contained 79.20 wt.% ZnO, representing the highest target-oxide concentration among the four materials. The waste SLS window glass contained 72.80 wt.% SiO_2, while the aluminium-can-derived precursor contained 70.20 wt.% Al_2O_3. The eggshell-derived precursor recorded 60.15 wt.% CaO. Despite the presence of secondary constituents, the relatively high concentrations of ZnO, SiO_2, CaO, and Al_2O_3 demonstrate the suitability of the selected wastes as precursor materials for the formulation of ZCAS glass.

CONCLUSION

The XRF characterization confirmed that the selected waste streams of used zinc based batteries, SLS window glass, eggshells, and aluminium cans can provide oxide precursors for zinc–calcium aluminosilicate (ZCAS) glass/glass-ceramic production. The used zinc based battery contained 79.20 wt.% ZnO, the waste SLS window-glass precursor contained 72.80 wt.% SiO_2, the eggshell contained 60.15 wt.% CaO, and the aluminium cans contained 70.20 wt.% Al_2O_3. The results shows that the target oxides were dominant despite the presence of minor constituents. The study confirm that waste streams can be processed into consistent useful oxide , supporting sustainable glass production pathways.

However, the influence of secondary oxides such as MnO, Fe_2O_3, and CO_2 on glass structure and performance requires further investigation to ensure safety.

RECOMMENDATIONS

i. Further studies should investigate optimization of the extraction procedures to increase the concentration and consistency of the target oxides.

ii. The chemical compositions obtained by XRF should be incorporated into batch calculations to improve control of the final glass composition.

iii. future work should evaluate the effects of precursor purity and residual minor constituents on the structural, thermal, mechanical, and biological properties of the resulting ZCAS glass-ceramic

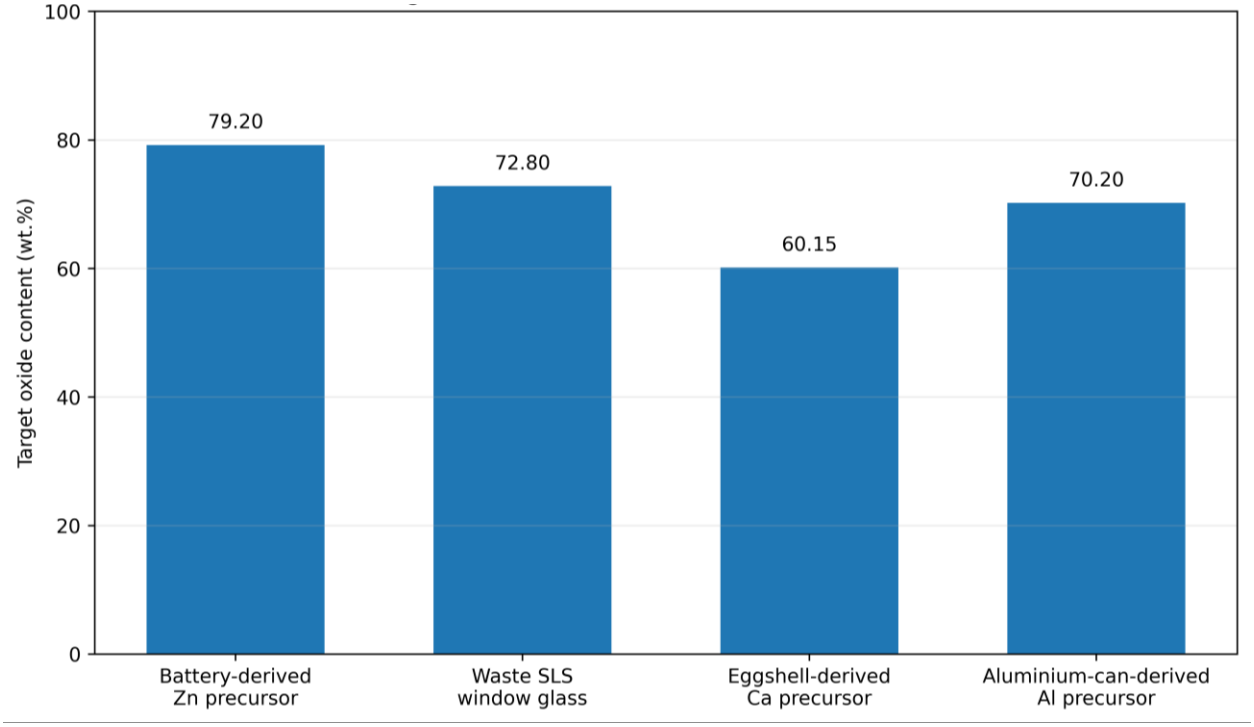


Figure 1: Target oxide content of the precursors

REFERENCES

Al-Buriahi, M. S., Kurtulus, R., Eke, C., Alomairy, S., & Olarinoye, I. O. (2024). An insight into advanced glass systems for radiation shielding applications: A review on different modifiers and heavy metal oxides-based glasses. Heliyon, 10(22), e40249. https://doi.org/10.1016/j.heliyon.2024.e40249.

Awogbemi, O., Inambao, F., & Onuh, E. I. (2020). Modification and characterization of chicken eggshell for possible catalytic applications. Heliyon, 6(10), e05283. https://doi.org/10.1016/j.heliyon.2020.e05283.

Awogbemi, O., Von Kallon, D. V., & Aigbodion, V. S. (2022). Pathways for sustainable utilization of waste chicken eggshell. Journal of Renewable Materials, 10(8), 2217–2246. https://doi.org/10.32604/jrm.2022.019152.

Azmiyawati, C., Niami, S. S., & Darmawan, A. (2019). Synthesis of silica gel from glass waste for adsorption of Mg^{2+}, Cu^{2+}, and Ag^{+} metal ions. IOP Conference Series: Materials Science and Engineering, 509, 012028. https://doi.org/10.1088/1757-899X/509/1/012028

Chen, L., & Dai, Y. (2016). Structure, physical properties, crystallization and sintering of iron-calcium-aluminosilicate glasses with different amounts of ZnO.

Journal of Non-Crystalline Solids, 452,45–49. https://doi.org/10.1016/j.jnoncrysol.2016.08.017

Colangelo, S. (2024). Reducing the environmental footprint of glass manufacturing. International Journal of Applied Glass Science, 15(4), 350–366. https://doi.org/10.1111/ijag.16674

Danewalia, S. S., Sharma, G., Thakur, S., & Singh, K. (2016). Agricultural wastes as a resource of raw materials for developing low-dielectric glass-ceramics. Scientific Reports, 6, 24617. https://doi.org/10.1038/srep24617

Hakeem, A. S., Wójcik, N. A., Wolff, S., & Ali, S. (2024). Evaluating the impact of ZnO doping on electrical and thermal properties of calcium-aluminosilicate oxynitride glass-ceramics. Ceramics International, 50(20, Part A), 37665–37675. https://doi.org/10.1016/j.ceramint.2024.07.125

Mohadi, R., Anggraini, K., Riyanti, F., & Lesbani, A. (2016). Preparation calcium oxide from chicken eggshells. Sriwijaya Journal of Environment, 1(2), 32–35. https://doi.org/10.22135/sje.2016.1.2.32-35

Mori, H. (2003). Extraction of silicon dioxide from waste colored glasses by alkali fusion using sodium hydroxide. Journal of Materials Science, 38(16), 3461–3468. https://doi.org/10.1023/A:1025100901693

Ni'mah, Y. L., Suprapto, S., Subandi, A. P. K., Yuningsih, N. E., & Pertiwi, A. C. (2022). The optimization of silica gel synthesis from chemical bottle waste using response surface methodology. Arabian Journal of Chemistry, 15(12), 104329. https://doi.org/10.1016/j.arabjc.2022.104329

Shil, T. C. (2016). Preparation of aluminum oxide from industrial waste can available in Bangladesh environment: SEM and EDX analysis. Journal of Advanced Chemical Engineering,6(2), 1–6. https://doi.org/10.4172/2090-4568.1000152

Subhani, S., Patel, M., & Rahaman, M. N. (2019). The role of alkali and alkaline-earth metals in silicate glass structure and properties: A review. International Materials Reviews, 64(5),257–285. https://doi.org/10.1080/09506608.2018.1503672

Yadav, V. K., Yadav, K. K., Cabral-Pinto, M. M. S., Choudhary, N., Gnanamoorthy, G., Tirth, V., Prasad, S., Khan, A. H., Islam, S., & Khan, N. A. (2021). The processing of calcium rich agricultural and industrial waste for recovery of calcium carbonate and calcium oxide and their application for environmental cleanup: A review. Applied Sciences, 11(9), 4212. https://doi.org/10.3390/app11094212

Yu, X., Wang, S., Zhu, J., Li, W., & Wang, Y. (2024). Environmentally friendly synthesis and performance evaluation of $CaO–Al_2O_3–SiO_2$ glass-ceramics derived from 100% waste. Journal of Cleaner Production, 452, 141675. https://doi.org/10.1016/j.jclepro.2024.141675

Zhao, L., Tang, M., & Xu, J. (2024). Advances in zirconia-doped silicate glasses for biomedical and optical applications. Materials Today Advances, 21, 100980.https://doi.org/10.1016/j.mtadv.2024.100980