

CHARACTERIZATION OF RICE HUSK ASH, WASTE GLASS, AND RECYCLED HIGH-DENSITY POLYETHYLENE AS WASTE- DERIVED SUSTAINABLE COMPOSITE HOPPER LINERS FOR THE CEMENT INDUSTRY

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ABSTRACT

Hoppers in cement factories are subjected to continuous abrasive wear from limestone and clinker, and the metallic and conventional polymeric liners currently used are costly to replace and environmentally burdensome. This study characterizes three waste-derived materials, rice husk ash (RHA), waste soda-lime glass (WG), and recycled high-density polyethylene (HDPE), to establish their suitability as constituents of a sustainable composite hopper liner. RHA and WG were sourced locally, processed by washing, drying, controlled combustion (RHA) or milling (WG), and analysed by X-ray fluorescence (XRF) to determine chemical composition. Recycled HDPE was sorted, washed, shredded and cryogenically ground, then examined by Fourier-transform infrared spectroscopy (FTIR) to confirm polymer identity and detect degradation. Scanning electron microscopy (SEM) was used to examine the microstructure of RHA and WG, while density, specific gravity, and bulk density were determined for all three materials. XRF results showed RHA contained 93.90% SiO₂ (84.62% amorphous) with low loss-on-ignition (4.6%), confirming a highly reactive, thermally stable pozzolanic filler, while WG was dominated by SiO₂ (72.5%), Na₂O (14%) and CaO (10%), consistent with typical soda-lime glass chemistry. FTIR spectra of the

recycled HDPE displayed the characteristic C–H stretching and bending bands (2913, 2847, 1465 and 721 cm^{-1}) expected of a polyethylene backbone, with a weak carbonyl-region absorption near 1742 cm^{-1} indicating minor oxidative degradation from prior service life. SEM micrographs revealed irregular, angular RHA particles with a porous cellular structure and irregular, sharp-edged WG particles favourable for mechanical interlocking in a polymer matrix. Physical property testing showed RHA and WG densities of 2.182 and 2.495 g/cm^3 respectively, both markedly higher than recycled HDPE (0.952 g/cm^3), while RHA displayed the lowest bulk density (0.40 g/cm^3), indicating high porosity. Taken together, the results indicate that RHA offers hardness- and wear-enhancing silica reinforcement, WG offers a hard, mechanically interlocking filler with pozzolanic secondary chemistry, and recycled HDPE offers a light, ductile, chemically stable matrix; the three waste streams are therefore chemically and physically complementary and are recommended as viable raw materials for a sustainable, low-cost composite hopper liner. Composite fabrication, blend optimization and comparative mechanical performance against conventional liner materials are reported in a companion study.

KEYWORDS: *Rice husk ash; Waste glass; Recycled HDPE; Waste valorization; Circular economy; Hopper liner; Composite reinforcement*

1. INTRODUCTION

Cement manufacturing remains one of the most important enablers of global infrastructural development, supplying the foundational material for the majority of construction projects worldwide (Panagoda et al., 2023). The production process depends on continuous handling and transportation of highly abrasive raw materials such as limestone, clay and clinker through hoppers, cyclones, chutes and conveyors. These handling points are subjected to relentless sliding and impact abrasion, and the internal liners that protect them wear out quickly, driving up maintenance costs and causing unplanned production stoppages (Ngangaa et al., 2023; Moges et al., 2025). Conventional hopper liners, fabricated from metal plates or unmodified engineering polymers, are frequently unable to withstand this combination of abrasive wear, impact loading, and continuous throughput, particularly in resource-constrained operating environments where replacement parts are costly and lead times are long.

Advances in composite materials science offer a pathway to more durable and cost-effective liner solutions. By deliberately combining reinforcing fillers with a polymeric matrix, it is

possible to engineer materials whose hardness, wear resistance, and toughness exceed those of either constituent alone (Alzubaidi et al., 2024). Mbishida et al., (2026) reported that a particularly attractive strategy, consistent with growing global emphasis on waste valorization and the circular economy, is to source these reinforcing fillers and matrix material from post-consumer and agro-industrial waste streams rather than virgin feedstocks. Three such waste streams are considered in this study: rice husk ash (RHA), an agricultural residue rich in amorphous silica; waste soda-lime glass (WG), a chemically durable and widely available post-consumer waste; and recycled high-density polyethylene (HDPE), a common thermoplastic packaging and container waste.

Globally, hundreds of millions of tonnes of rice are milled annually, and roughly 20% of the paddy mass is discarded as husk, which on open burning or uncontrolled disposal contributes to air pollution and greenhouse gas emissions (Azman et al., 2024; Ro et al., 2024). Converting this husk into ash under controlled combustion instead yields an amorphous, silica-rich pozzolan that has already found extensive use as a supplementary cementitious material, with recent life-cycle assessments confirming meaningful reductions in embodied CO₂ when RHA displaces virgin materials in construction applications (Phatak & Kishor, 2024; Ro et al., 2024). Waste glass similarly accumulates in large volumes in municipal solid waste streams, and although a portion is recycled into new glass products, a substantial fraction is not suitable for remelting and is instead landfilled, a non-biodegradable burden that recent reviews continue to highlight as an under-exploited resource for construction and polymer composite applications (Siddika et al., 2021). Waste HDPE, likewise, is one of the most commonly discarded thermoplastics, and mechanical recycling routes that convert it into reinforced composites are now widely investigated as a lower-energy alternative to virgin polymer production, consistent with circular-economy principles (Pilapitiya & Ratnayake, 2024; Peti et al., 2025).

Previous investigations have explored these three materials both individually and in various combinations. Waste glass powder has been shown to improve the hardness, thermal stability and wear behaviour of polymer matrices (Zhang et al., 2021; Naguib & Baig, 2021), while rice husk ash has been reported to enhance the abrasion resistance and mechanical strength of HDPE and related thermoplastics because of its high silica content (Zhang et al., 2018; Ali & Qazi, 2021). Recycled HDPE composites reinforced with waste glass powder have achieved tensile strengths and hardness values suitable for pipe and structural applications (Yaduwanshi et al., 2023), and recent tribological studies confirm that filler incorporation can meaningfully alter the friction and wear behaviour of HDPE-based blends (Alejo-Martínez et

al., 2025). However, the specific combination of RHA, WG and recycled HDPE as a hybrid ternary system, characterized and evaluated explicitly for hopper-liner service in cement plants, remains comparatively under-studied, and most reported work has not established, at the raw-material level, the precise chemical, microstructural and physical properties that justify the selection of these three particular waste streams for this application.

This paper addresses that gap by presenting a detailed characterization of RHA, WG and recycled HDPE as candidate raw materials for a sustainable composite hopper liner. The specific objectives are to: (i) determine the chemical composition of RHA and WG by X-ray fluorescence; (ii) confirm the polymer identity and condition of the recycled HDPE by Fourier-transform infrared spectroscopy; (iii) examine the microstructure of RHA and WG by scanning electron microscopy; (iv) determine the density, specific gravity and bulk density of all three materials; and (v) evaluate, on the basis of these results, the sustainability credentials and composite reinforcement potential of each waste stream for hopper-liner service in the cement industry. Consistent with this scope, the fabrication of RHA–WG–HDPE composite blends, their optimization by Response Surface Methodology, and their comparative mechanical performance against a conventional liner material are deliberately outside the scope of this paper and are reported in a companion study currently in preparation.

2. MATERIALS AND METHODS

2.1 Materials and Sourcing

Three waste-derived materials were investigated: recycled high-density polyethylene (HDPE) sourced from discarded plastic containers and industrial HDPE waste sites within Bauchi Metropolis, Nigeria; rice husk collected from Yelwa Market, Bauchi, for conversion to rice husk ash (RHA); and discarded soda-lime glass bottles collected from local waste collection points in Yelwa, Bauchi, for conversion to waste glass powder (WG). All three materials are widely and cheaply available as post-consumer or agro-industrial waste in the study locality, which is consistent with the objective of developing a low-cost, locally sourced liner material.

2.2 Sample Preparation

2.2.1 Preparation of Recycled HDPE

The collected HDPE waste was sorted to remove non-HDPE contaminants, washed with detergent and distilled water, and oven-dried at 60 °C for 4 hours, following the procedure recommended by Nwabunma and Kyu (2008). The dried material was shredded into flakes

using an industrial plastic shredder and then subjected to cryogenic grinding in liquid nitrogen ($-196\text{ }^{\circ}\text{C}$) to produce a uniform powder, which was sieved through a $300\text{ }\mu\text{m}$ sieve.

2.2.2 Preparation of Rice Husk Ash

Rice husk was washed with distilled water to remove grit and oven-dried at $100\text{ }^{\circ}\text{C}$ for 2 hours. The dried husk was combusted in a kiln at $600\text{ }^{\circ}\text{C}$ for 6 hours, with the temperature ramped at $50\text{ }^{\circ}\text{C}$ per hour, in order to obtain amorphous ash; Damanhuri et al. (2020) note that controlled combustion below $700\text{ }^{\circ}\text{C}$ favours an amorphous ash structure, whereas temperatures above $800\text{ }^{\circ}\text{C}$ promote crystallization, which is less reactive as a filler. The resulting ash was ground for 20 minutes and sieved through a $75\text{ }\mu\text{m}$ sieve.

2.2.3 Preparation of Waste Glass

Waste soda-lime glass bottles were washed to remove dirt, labels and organic contaminants, then oven-dried at $100\text{ }^{\circ}\text{C}$ for 2 hours. The dried glass was broken into smaller pieces with a hammer mill and further reduced using a ball mill for 30 minutes, before being sieved through a $150\text{ }\mu\text{m}$ sieve. Ishaq et al. (2026) reported that finely ground waste glass below $150\text{ }\mu\text{m}$ enhances mechanical strength and wear resistance when used as reinforcement in composite systems, which informed the target particle size adopted here. The sieved powder was stored in an airtight container to minimize moisture pick-up prior to characterization.

2.3 Characterization Techniques

2.3.1 Chemical Composition (X-ray Fluorescence)

The chemical composition of RHA and WG was determined following ASTM C114-18 (2018), the standard method for chemical analysis of hydraulic cement. Powdered samples were oven-dried at $110\text{ }^{\circ}\text{C}$ for 2 hours to remove residual moisture, and 5 g of each sample was blended with boric acid as a binder. The mixture was compressed at 20 MPa into a 30 mm diameter pellet suitable for X-ray fluorescence (XRF) analysis, and the elemental oxide composition was recorded directly from the XRF instrument.

2.3.2 Fourier-Transform Infrared Spectroscopy (FTIR)

Because HDPE has a relatively low melting point and would soften under the thermal conditions of pellet-based XRF analysis, FTIR was used instead to characterize the recycled HDPE. Spectra were recorded on a Perkin Elmer Spectrum 100 FT-IR spectrometer operating in attenuated total reflectance (ATR) mode over the range $4000\text{--}400\text{ cm}^{-1}$, following the procedure of Olajide (2018). Approximately 0.2 mg of specimen was placed on a KBr plate for analysis.

2.3.3 Scanning Electron Microscopy (SEM)

Microstructural analysis of RHA and WG was carried out using a PhenomTM ProX scanning electron microscope. Samples were sputter-coated with a thin gold layer using a Quick Coater Metalizer (Sanyu Electron SC-701) to render them conductive, and micrographs were captured under vacuum with magnification, focus, contrast and brightness optimized for clarity, following the approach of Shehu (2016).

2.3.4 Physical Properties: Density, Specific Gravity and Bulk Density

Density was determined for each material by the Archimedean principle: sample mass was measured on a digital balance and sample volume by water displacement in a calibrated cylinder, following Hughes (2005). Specific gravity was determined by the pycnometer method in accordance with ASTM D792 and ASTM D854, comparing the weight of each material with the weight of an equal volume of water. Bulk density was determined in accordance with ASTM C29/C29M (2023).

3. RESULTS AND DISCUSSION

3.1 Chemical Composition of Rice Husk Ash

Table 1 presents the XRF-derived chemical composition of the RHA used in this study.

Table 1: Chemical composition of rice husk ash. (RHA)

Chemical constituent	Content (%)	Chemical constituent	Content (%)
SiO ₂	93.90	Fe ₂ O ₃	0.58
CaO	0.50	SO ₃	0.08
Na ₂ O	0.23	Cl	0.26
MgO	0.61	TiO ₂	0.07
MnO	0.11	P ₂ O ₅	0.33
Al ₂ O ₃	0.73	LOI	4.60
K ₂ O	2.61	Amorphous SiO ₂	84.62

The RHA contained 93.90% SiO₂, of which 84.62% was in the amorphous form, indicating a highly reactive pozzolanic material. Zhang et al. (2021) reported that such high silica content increases the hardness, wear resistance and compressive strength of composites into which RHA is incorporated. Minor constituents, Al₂O₃ (0.73%) and Fe₂O₃ (0.58%), are expected to contribute additional structural integrity when RHA is combined with waste glass and a polymer matrix, while the low loss-on-ignition value (4.6%) indicates minimal residual organic/carbon impurity and confirms that the ash is thermally stable and will not introduce

volatile combustible content into a composite exposed to elevated in-service temperatures (Damanhuri et al., 2020). The presence of K_2O (2.61%) alongside the dominant silica fraction is also expected to contribute to the abrasion resistance required for handling limestone in cement hoppers (Rao et al., 2017).

3.2 Chemical Composition of Waste Glass

Table 2 presents the XRF-derived chemical composition of the waste soda-lime glass.

Table 2: Chemical composition of waste soda-lime glass. (WG)

SiO_2	Na_2O	CaO	MgO	Al_2O_3	K_2O	Fe_2O_3	SO_3	LOI
72.5	14.0	10.0	3.5	1.25	0.5	0.25	0.25	Negligible

The waste glass was dominated by SiO_2 (72.5%), with Na_2O (14%) and CaO (10%) as the principal secondary oxides, a composition consistent with typical soda-lime container glass. Beyond its contribution to mechanical strength, thermal stability and wear resistance, the Na_2O fraction is reported to act as a fluxing agent that improves dispersion of glass particles within an HDPE matrix, while CaO contributes to abrasion resistance, both properties directly relevant to continuous material flow inside a hopper liner (Rao et al., 2017; Memon et al., 2017). The 3.5% MgO content is expected to improve crack resistance, and the minor oxides K_2O , Fe_2O_3 and SO_3 (0.5%, 0.25% and 0.25% respectively) are expected to play a secondary role in chemical durability.

3.3 Physical Properties of RHA, Waste Glass and Recycled HDPE

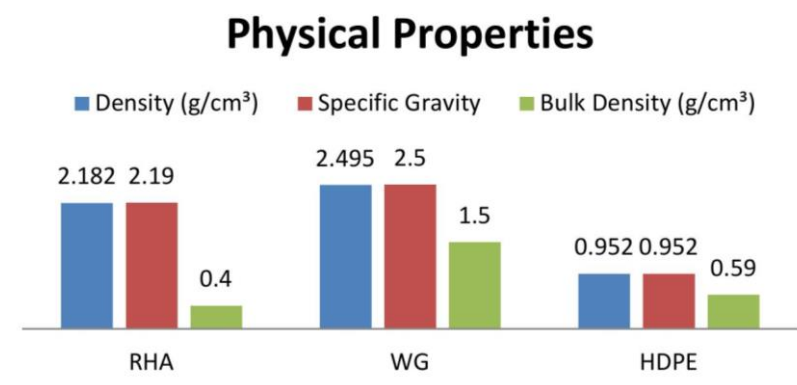


Figure 1: Density, specific gravity and bulk density of RHA, waste glass and recycled HDPE As can be seen in Figure 1, the density values obtained for RHA, WG and recycled HDPE were 2.182, 2.495 and 0.952 g/cm³ respectively.

The density of RHA is consistent with its silica-dominated composition, which is known to elevate density relative to purely organic agricultural residues (Kumar et al., 2022). The density of WG (2.495 g/cm³) falls within the typical 2.4–2.6 g/cm³ range reported for soda-lime glass (Sanni et al., 2021), while the recycled HDPE density (0.952 g/cm³) is consistent with the established 0.94–0.97 g/cm³ range for HDPE and confirms that the recycling and grinding process did not materially alter the intrinsic density of the polymer (Ahmed et al., 2023).

Specific gravity followed the same ranking (RHA 2.19, WG 2.50, HDPE 0.952), consistent with the presence of amorphous silica and residual carbon in RHA (Singh & Mehta, 2020) and the silicate network of WG (Oluwafemi et al., 2021), while the lower specific gravity of HDPE confirms its suitability as a lightweight matrix where composite mass reduction is desirable (Mohammed et al., 2022). Bulk density values of 0.40, 1.50 and 0.59 g/cm³ were recorded for RHA, WG and HDPE respectively. The notably low bulk density of RHA reflects its fine, porous, low-packing-density particle structure (Kumar et al., 2022), a property that is favourable for lightweight composite formulations, whereas the higher bulk density of WG reflects its denser, more angular particle packing typical of crushed glass (Sanni et al., 2021).

3.4 Microstructural (SEM) Characteristics of RHA and Waste Glass

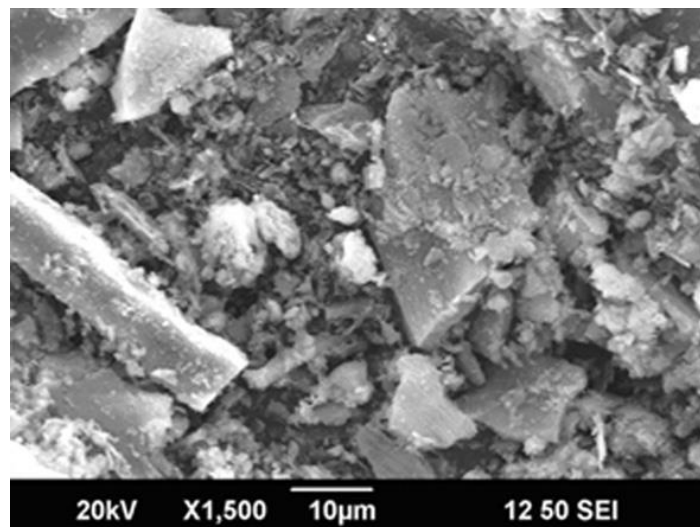


Figure 2: SEM micrograph of rice husk ash (20 kV, ×1,500, 10 µm scale bar)

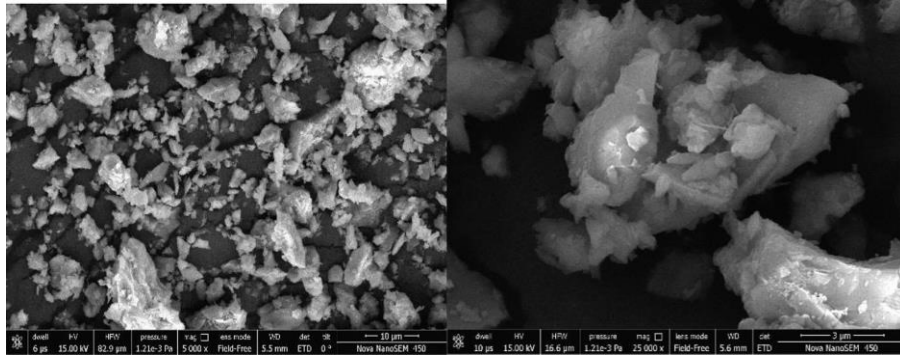


Figure 3: SEM micrographs of waste glass at two magnifications. ($\times 5,000$ and $\times 25,000$)

The SEM micrograph of RHA (Figure 2) reveals irregular, angular particles with a porous, cellular surface texture, consistent with the microporous silica skeleton that remains after the organic fraction of the husk (cellulose and lignin) is burned away during controlled combustion. This porous, high-surface-area morphology is characteristic of amorphous RHA and is expected to promote mechanical interlocking with a surrounding polymer matrix, in addition to contributing pozzolanic reactivity where relevant (Blayi et al, 2025; Singh, 2018). The SEM micrographs of WG (Figure 3), captured at two magnifications, show sharp-edged, irregularly fractured particles typical of milled glass. The angular, high-aspect-ratio fragments observed at higher magnification suggest a strong potential for mechanical keying into a polymer matrix, which is consistent with reports that finely milled glass improves the wear resistance of polymer composites through such interlocking (Ishaq et al., 2026; Zhang et al., 2021).

3.5 Functional Group (FTIR) Characteristics of Recycled HDPE

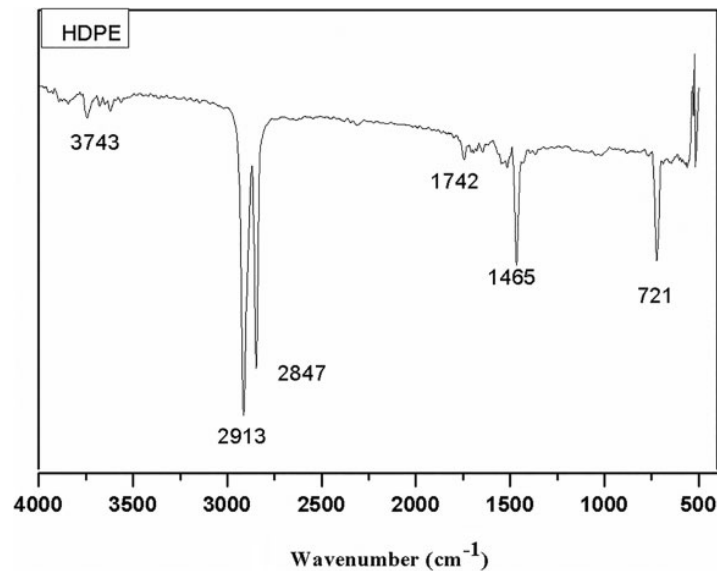


Figure 4: FTIR spectrum of recycled HDPE.

The FTIR spectrum of the recycled HDPE (Figure 4) displayed a strong doublet at 2913 and 2847 cm^{-1} , corresponding to asymmetric and symmetric C–H stretching vibrations, and a further band at 721 cm^{-1} associated with C–H rocking vibrations, both of which are the classic fingerprint absorptions of a polyethylene backbone. A moderate band at 1465 cm^{-1} corresponds to C–H bending, and these peak positions are in good agreement with previously reported HDPE spectra (Olajide, 2018). A weak absorption near 1742 cm^{-1} , in the carbonyl stretching region, together with the shoulder near 3743 cm^{-1} attributable to O–H groups, indicates a small degree of oxidative degradation consistent with the prior service life and environmental exposure of the recycled feedstock. Such oxidation-related carbonyl absorption has previously been associated with a modest reduction in molecular weight and consequent effects on tensile and impact performance; a reduction in the intensity of the 721 cm^{-1} crystalline band after composite formation is also reported to indicate an increase in amorphous content, which can improve toughness at some cost to tensile strength. Overall, the spectrum confirms that the recycled feedstock retains the essential chemical identity of virgin HDPE, with only minor evidence of degradation, supporting its suitability as a composite matrix material.

3.6 Sustainability Credentials of the Waste-Derived Materials

3.6.1 Rice Husk Ash

Global rice production is estimated at roughly 700 million tonnes annually, and rice husk constitutes about 20% of paddy mass, generating an enormous volume of residue that is frequently disposed of by open burning (Azman et al., 2024). Open burning of husk releases particulate matter and greenhouse gases and is a recognized contributor to regional air-quality problems in rice-producing areas. Converting husk to ash under controlled combustion, as adopted in this study, both prevents this uncontrolled burning and produces a material with genuine engineering value: recent life-cycle-based assessments confirm that RHA utilization can meaningfully lower the carbon footprint of construction materials, in some cases by tens of per cent relative to conventional alternatives, while simultaneously addressing agricultural waste management (Mbishida et al., 2026; Ro et al., 2024; Phatak & Kishor, 2024). Diverting RHA into a composite hopper liner, rather than construction cement replacement alone, extends this valorization pathway into a new, higher-value engineering application and further supports circular-economy objectives in rice-producing regions such as northern Nigeria.

3.6.2 Waste Glass

Waste glass is a major, non-biodegradable component of municipal solid waste; historical estimates indicate that tens of millions of tonnes of waste glass are generated annually worldwide, and a substantial fraction is unsuitable for remelting into new glass and is instead landfilled (Bolden et al., 2013; EPA, 2023). Because glass does not readily degrade in the environment, diverting it into engineering applications such as polymer composite reinforcement offers a durable disposal pathway that avoids long-term landfill accumulation. Recent reviews by Mbishida et al., (2026) and Siddika et al., (2021) has identified waste glass valorization in construction and composite materials as an important and still under-exploited avenue for reducing landfill burden while recovering genuine mechanical value from an otherwise discarded resource, since the same hardness and chemical durability that make glass difficult to degrade also make it a mechanically favourable filler once it is finely milled.

3.6.3 Recycled High-Density Polyethylene

Plastic packaging waste, including HDPE containers, represents one of the largest and fastest-growing components of the global solid waste stream, and mechanical recycling remains one of the most energy-efficient recovery routes available for thermoplastics because it avoids the energy-intensive depolymerization required by chemical recycling (Pilapitiya & Ratnayake, 2024; Peti et al., 2025). The FTIR results in this study confirm that the recycled HDPE retains its essential polyethylene chemistry despite prior service life, indicating that mechanical recycling of this waste stream yields a matrix material of adequate quality for composite manufacture. Recent tribological and mechanical studies of recycled-HDPE-based composites confirm that filler incorporation is an effective strategy for recovering or enhancing the performance lost during recycling, supporting the use of recycled rather than virgin HDPE as the composite matrix in this application (Alejo-Martínez et al., 2025; Webo et al., 2025).

3.7 Potential of RHA, Waste Glass and Recycled HDPE as Composite Hopper Liner Constituents

Considered together, the characterization results indicate that the three waste streams are chemically and physically complementary for hopper-liner composite fabrication. RHA supplies a high-silica, amorphous, porous filler expected to raise hardness, wear resistance and thermal stability while contributing minimal density penalty, consistent with the well-established role of silica-rich agricultural fillers in wear-resistant polymer composites (Mbishida et al., 2026; Zhang et al., 2018). Waste glass supplies a denser, angular, chemically durable filler whose sharp-edged particle morphology favours mechanical

interlocking within the polymer matrix and whose secondary oxide chemistry (Na_2O , CaO , MgO) is expected to assist particle dispersion and further improve abrasion resistance (Rao et al., 2017; Memon et al., 2017). Recycled HDPE, confirmed by FTIR to retain its essential polymer identity, supplies a low-density, ductile matrix capable of absorbing impact energy and accommodating the rigid RHA and WG fillers without excessive embrittlement, consistent with prior reports that HDPE contributes flexibility and impact resistance rather than hardness in filled composite systems (Osseni et al., 2020).

From an application standpoint, cement hopper liners must resist combined sliding abrasion and impact loading from limestone and clinker while remaining light enough to avoid unnecessary structural loading and affordable enough for routine replacement in resource-constrained plants. The measured densities of RHA (2.182 g/cm^3) and WG (2.495 g/cm^3) are both well below those of conventional metallic liner materials, so that even a filler-rich formulation is expected to remain considerably lighter than a metal liner, while the amorphous silica of RHA and the mechanically interlocking particle geometry of WG together address the hardness and wear-resistance requirements that motivate this study. On this basis, the three materials characterized here are judged to be suitable raw-material candidates for a sustainable composite hopper liner, and the specific blend ratios required to optimize hardness, wear resistance, impact resistance and density simultaneously are addressed through Response Surface Methodology in a companion development study.

4. CONCLUSION

This study characterized rice husk ash, waste soda-lime glass, and recycled high-density polyethylene as candidate raw materials for a sustainable composite hopper liner in the cement industry. XRF analysis confirmed that RHA is a highly reactive, silica-rich (93.90% SiO_2 , 84.62% amorphous) pozzolanic filler with low organic impurity, while waste glass exhibited a typical soda-lime chemistry dominated by SiO_2 (72.5%), Na_2O (14%) and CaO (10%). FTIR analysis confirmed that the recycled HDPE retained its essential polyethylene chemical identity, with only minor evidence of oxidative degradation from prior service life. SEM imaging revealed a porous, angular RHA microstructure and a sharp-edged, mechanically interlocking WG particle morphology, both favourable for reinforcement of a polymer matrix. Physical property testing showed that RHA and WG are considerably denser than recycled HDPE, while RHA exhibited the lowest bulk density of the three materials, reflecting its high porosity. Collectively, these results demonstrate that RHA, WG and recycled HDPE possess complementary chemical, microstructural and physical

characteristics, and that all three waste streams carry established sustainability credentials as agricultural or post-consumer waste diverted from open burning, landfill, or virgin-resource consumption. The materials are therefore recommended as viable constituents of a hybrid composite hopper liner, with composite fabrication, blend optimization and mechanical performance evaluation to be reported in a companion study.

Declarations

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Conflict of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability: The characterization data supporting the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Conceptualization, Methodology, Investigation, Writing (original draft) – Engr. M. A. Mbishida (Phd In-view); Supervision – Prof. M. H. Muhammad, Prof. J.S. Jacob, and Dr. N. Muhammad; Final Writing (Review & Editing) – all authors.

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