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Sustainable Innovation: The Utilization of Waste Glass As A Glazing Material in Ceramic Surface Treatment

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ABSTRACT

The application of glaze not only imparts a distinctive visual impact but also enhances the strength of ceramic. The procurement of raw materials for glaze preparation incurs significant costs. In contrast, waste glass has the potential to serve as a viable alternative to ceramic surface treatment. Glass possesses comparable characteristics to glaze, which is derived from a substance composed of silica (SiO2). The cost-effectiveness and diverse colour range of waste glass have been observed. The present composition aims to elucidate the investigation into the viability of waste glass as a substitute substance for glaze in the realm of ceramic art.

Keywords: Glass, glaze, surface treatment, ceramic art

1. INTRODUCTION

A significant amount of glass material is often wasted without being fully utilized. Furthermore, this material possesses the ability to be recycled and can serve as a viable substitute for creating glaze on ceramic surfaces. This material is well-suited for ceramic entrepreneurs and ceramic artisans to create commercial and artistic artworks, as it does not necessitate a significant amount of expenditure. Sustainable development necessitates collaborative endeavours to construct a future that is sustainable, inclusive, and resilient for both humanity and the environment. The achievement of sustainable development necessitates the harmonisation of three fundamental components: economic growth, social inclusion, and environmental protection. This study primarily emphasises Goal 12, which pertains to responsible consumption and production, waste reduction through prevention, reduction, recycling, and reuse, and the promotion of sustainable practices. It aligns with the objectives of the SDG campaign.

Various types of waste glass can be utilized, including but not limited to food storage containers (such as bottles and jars), tableware items (such as plates, cups, and glasses), and other waste materials like broken glass windows. The waste materials typically originate from prior recycling procedures, and this particular sort of material is deemed most appropriate for this study because of its lower melting temperatures.

2. LITERATURE REVIEW

2.1 Glass Characteristic

Glass has held a continuous presence in human civilization, serving both functional and aesthetic purposes since antiquity. Historically, its translucency and ability to manipulate light positioned it as a material of both utility and wonder, from ancient vessels and stained-glass windows to modern architectural façades. In contemporary art and design, this duality persists, glass continues to embody a complex intersection of material science, sensory experience, and symbolic meaning. Its use has shifted from merely decorative or utilitarian applications toward more conceptual and ecological frameworks, where material transformation becomes a metaphor for renewal, continuity, and sustainability.

In the context of the United Nations Sustainable Development Goal 12, which promotes responsible consumption and production, glass serves as a critical material for sustainable art practices. Its recyclability and chemical stability enable a circular creative process, one where discarded glass waste is reimagined as a valuable artistic resource. This transformation challenges conventional hierarchies of materials by blurring the boundary between waste and value. Recycled glass, therefore, functions as a powerful narrative medium that encapsulates environmental consciousness and aesthetic innovation simultaneously (Lakhouit, 2025).

From a scientific standpoint, glass is a non-crystalline, inorganic solid composed primarily of silica (SiO_2) that achieves its amorphous form through the rapid cooling of molten materials. The cooling process prevents the formation of crystalline structures, producing the unique optical and physical properties that distinguish glass from other solids. The predominant industrial formulation, soda-lime-silica glass, is composed of silica, sodium carbonate (Na_2CO_3), and calcium carbonate ($CaCO_3$), which collectively determine its stability, strength, and ease of processing. However, the same chemical logic applies when working with recycled glass cullet, allowing artists to re-melt and reconfigure glass into new material expressions while significantly reducing environmental impact. This adaptability has encouraged experimental approaches in studio-based art research, where artists explore the chemical and aesthetic potential of recycled glass as both subject and substance.

Fluxing agents, such as sodium oxide, are used to lower the melting point of silica, reducing the high energy demands of glass production. Lime (CaO) enhances durability and chemical resistance, although excessive amounts can lead to devitrification, a crystallization process that diminishes clarity and surface quality (Khattab, 2025). Artists who work with recycled glass often embrace these imperfections as aesthetic features rather than technical flaws, using devitrification, air bubbles, and uneven textures as expressive elements that reflect the transformation of discarded matter into new cultural artefacts. This approach aligns with broader artistic movements that advocate for material honesty and ecological authenticity, positioning the trace of the process as part of the artwork's meaning (Adams, 2020).

Coloration in glass is another domain where scientific precision meets artistic intention. The introduction of metallic oxides, such as cobalt, copper, chromium, manganese, or iron, generates a spectrum of vibrant hues. Cobalt oxide produces deep, luminous blues; copper yields green and turquoise tones; and chromium creates bright greens and yellows (Rossano, 2022). These chromatic variations depend on both chemical composition and kiln atmosphere, offering the artist a palette that is simultaneously chemical, optical, and emotional. In recycled glass practices, coloration also becomes symbolic, it signifies transformation, recovery, and the poetic reinvention of waste. The material's ability to change state, from solid to molten to solid again, becomes a metaphor for resilience and regeneration within the ecological narrative of sustainable art.

Recent scholarship situates recycled glass at the convergence of sustainability, aesthetics, and material culture. These practices align with circular economy principles, which emphasize the continual reuse and revalorization of materials within production cycles. In artistic research, this manifests as a shift toward studio ecologies, creative environments that mimic natural systems of renewal, where waste is treated as raw material for further transformation. Through this lens, the act of melting, fusing, and reshaping glass mirrors ecological processes of decay and rebirth, rendering artistic creation an act of environmental reflection.

The aesthetic and conceptual potential of recycled glass lies not only in its visual beauty but also in its capacity to embody environmental ethics. Each sherd of discarded glass carries a narrative of consumption, discard, and revival, its reformation into art symbolizes humanity's ability to rethink its relationship with material culture and the planet. Within this framework, glass functions as both a medium and message: a transparent archive of environmental history and a material proposition for sustainable futures. By merging scientific knowledge with artistic sensibility, practitioners position recycled glass as an active participant in ecological discourse, an evolving material language that invites reflection, responsibility, and renewal.

2.2 Glaze in Ceramics

Ceramic glazing represents one of the most transformative processes in the evolution of clay-based art and material culture. It merges scientific precision with artistic experimentation, producing surfaces that are both functionally durable and aesthetically expressive. Historically, glazes have symbolized the union between art and chemistry, a meeting point where the raw material of the earth is refined through human ingenuity and the controlled forces of fire. Early glazes, dating back to ancient Egypt, Mesopotamia, and China, were primarily accidental discoveries: mineral-rich slips that vitrified under heat, giving pottery its characteristic sheen and water resistance. Over millennia, these discoveries evolved into deliberate chemical formulations, reflecting both technological advancement and aesthetic ambition in human civilization.

At its core, a ceramic glaze is a finely powdered suspension of minerals that, when applied to a bisque-fired clay body, forms a thin glassy layer after firing. The process involves applying the glaze through brushing, dipping, pouring, or spraying, allowing the liquid mixture to adhere evenly to the ceramic surface. During firing, the glaze undergoes complex thermochemical reactions, melting, diffusion, and vitrification, that result in a continuous glass phase strongly bonded to the underlying clay body. The result is not merely a coating but a molecular integration that seals, strengthens, and beautifies the ceramic object.

From a materials science perspective, glaze composition is typically structured around three principal components: glass-formers, fluxes, and stabilizers;

- Glass-formers, primarily silica (SiO_2), constitute the structural framework of the glaze. Silica provides the fundamental network that, when melted, creates the vitreous surface responsible for gloss, transparency, and hardness. However, due to silica's high melting point (approximately 1,710 °C), pure silica glazes are rarely practical.
- Fluxes, such as sodium oxide (Na_2O), potassium oxide (K_2O), and calcium oxide (CaO), are added to lower the melting temperature, allowing the glass to form at standard kiln ranges (between 1,000 °C and 1,300 °C). These compounds act as "melting facilitators," promoting fluidity during firing and helping the glaze bond effectively to the clay substrate.
- Stabilizers, particularly alumina (Al_2O_3) derived from clay or feldspar, prevent excessive glaze flow during the melt and improve surface durability, scratch resistance, and thermal stability. The proportions and interactions of these components determine the glaze's optical clarity, surface texture, and adherence to the ceramic body (Reed, 2021).

The chemical reactions that occur during firing are central to the glaze's performance. At elevated temperatures, the fluxes interact with silica to form silicates, while alumina modifies the network, improving viscosity and preventing devitrification, the unwanted crystallization that causes a dull or opaque surface. This dynamic interplay of chemistry and temperature underpins the expressive potential of glazes, allowing for infinite variation in colour, transparency, and surface quality.

Ceramic glazes perform both aesthetic and utilitarian functions. Aesthetically, they transform the clay body into a vibrant visual surface capable of expressing colour, texture, depth, and luminosity. The reflective and refractive qualities of glaze amplify the interaction between light and form, producing effects that range from translucent delicacy to saturated opacity. Functionally, glazes create an impermeable layer that seals the porosity of the clay, rendering it water-resistant and suitable for domestic, architectural, or sculptural use. The glaze thus embodies a dual identity: it is both a skin and a shield**,** protecting the vessel while defining its visual and tactile presence.

The introduction of metallic oxides into glaze formulation represents one of the most significant artistic innovations in ceramic history. Cobalt oxide yields deep, luminous blues; copper produces green or turquoise tones; iron provides earth reds and browns; while manganese, chromium, and titanium oxides generate purples, yellows, and subtle surface iridescence (Rossano, 2022). The colour development depends not only on the oxide concentration but also on the firing atmosphere, oxidizing or reducing, which alters the valence state of the metal ions. This relationship between chemistry and colour transforms the kiln into an active site of creation, where scientific phenomena translate into artistic expression. The unpredictability of glaze outcomes, drips, cracks or uneven coloration, often becomes an aesthetic strategy in contemporary ceramic practice, symbolizing material vitality and the co-agency of nature in the creative process.

3. METHODOLOGY

Three types of recycled waste glass, clear, green, and brown were selected as the primary experimental materials. The green glass was obtained from discarded beverage bottles, the clear glass originated from broken window fragments, and the brown glass was sourced from used drinking glasses. The use of these post-consumer materials aligns with the study's aim to explore sustainable reuse of glass waste in ceramic surface decoration and glaze development. The glass samples were cleaned thoroughly with detergent and distilled water to remove dust, grease, and other contaminants. After drying, the glass was manually crushed using a mortar and pestle into small fragments.

The base substrate for this experiment consisted of stoneware clay, selected for its high firing strength, low porosity, and thermal compatibility with glass materials. The clay was shaped into test tiles measuring 5 cm × 5 cm × 1 cm, followed by bisque firing at 900°C for 8 hours to remove chemically bound water and organic matter.

After bisque firing, each tile was lightly sanded and cleaned to ensure a smooth surface. The prepared glass fragments were then carefully positioned at the centre of each bisque-fired tile surface to evaluate the localized interaction and melting behaviour between the glass and ceramic body.

The samples were fired in an furnace (maximum capacity of 1200°C) using a controlled firing schedule. The firing process consisted of the following stages:

- Initial heating: A gradual temperature increases from room temperature to 600°C at a ramp rate of 3°C/min to prevent thermal shock.
- Mid-range heating: Continued heating from 600°C to 1000°C at a ramp rate of 5°C/min to facilitate partial vitrification of the clay body.
- Peak firing: The temperature was raised from 1000°C to 1200°C at a rate of 2°C/min and held for 1 hour at peak temperature to allow complete melting and fusion of the glass fragments.

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- Cooling: Controlled cooling to room temperature at a rate of 4°C/min to minimize cracking and ensure stable glass-ceramic bonding.

The total firing duration was approximately 9 hours, including the heating, soaking, and cooling phases. This methodology aims to investigate how recycled glass of different compositions and colours behaves under high-temperature ceramic firing conditions. The results are expected to provide insight into the aesthetic potential, chemical interaction, and surface modification mechanisms of recycled glass when fused with ceramic substrates. Beyond the scientific analysis, the study contributes to the advancement of sustainable material practices and eco-conscious innovation in ceramic art and design.

4. ANALYSIS

Upon completion of the high-temperature firing at 1200°C**,** distinct visual and surface transformations were observed across the three types of recycled glass, clear, green, and brown**.** Each glass exhibited unique melting behaviours and colour responses, largely attributed to its inherent chemical composition and colorant oxides.

The clear glass melted evenly and produced a translucent, glossy surface layer with a subtle pooling effect at the centre of the stoneware substrate (refer Image 1). Its transparency allowed partial visibility of the underlying clay texture, generating an effect reminiscent of a thin glaze layer.

Image 1: Clear glass, and after firing result

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In contrast, the green glass, produced a more fluid melt. During firing, this glass demonstrated a lower viscosity and spread more widely across the surface (refer Image 2). The resultant fused layer displayed variations of emerald to olive green hues, with localized darkening at the contact zones between glass and clay. This effect suggests chemical diffusion and ionic exchange between the glass and the iron-bearing minerals in the stoneware body.

Image 2: Green Glass, and after firing result

The brown glass underwent partial crystallization during the cooling stage. This behaviour resulted in the formation of a semi-opaque, amber-toned layer with visible microcrystalline inclusions. These inclusions contributed to a matte, textural finish, providing a tactile quality distinct from the glossy surface of clear glass. The occurrence of microcrystals is indicative of devitrification, a process typical in high-iron glass compositions under controlled cooling rates (refer Image 3).

Image 3: Brown Glass, and after firing result

5. DISCUSSION

Beyond material performance, the experiment reveals the aesthetic potential of recycled glass as a sustainable decorative medium in ceramic art (refer Image 4). However, when examined through the lens of ceramic glaze science, the outcomes also align with established principles of glaze behavior particularly flux activity, viscosity changes, and phase separation.

Recycled glass, predominantly silica with varying levels of sodium, calcium, and other modifiers, acts as a low-melting flux within the ceramic matrix. Its spontaneous melting patterns correspond to the behaviour of high-flux glazes, where rapid viscosity reduction during firing produces runoff, pooling, and gradient formation. The observed tonal variations are indicative of localized differences in melt thickness and cooling rates, phenomena well-documented in glaze crystallization and devitrification studies. Similarly, the formation of irregular textures can be interpreted as the result of incomplete dissolution of glass fragments, echoing principles of inclusions and phase separation known in glaze chemistry.

From an artistic perspective, these scientifically grounded transformations extend beyond surface decoration. The unpredictability of recycled glass melt shaped by its heterogeneous composition introduces an element of controlled chance, a concept frequently explored in contemporary ceramic art. The resulting visual effects evoke natural geological processes such as lava flow, mineral crystallization, and erosion, thereby positioning the kiln as an analogue for geological time. This reinforces a conceptual narrative in which material transformation embodies ecological awareness, suggesting that waste materials can be reintegrated not merely as sustainable substitutes but as active contributors to artistic meaning.

Thus, the outcomes demonstrate a productive convergence of scientific glaze behaviour and artistic interpretation. By situating the recycled glass effects within established ceramic glaze theory while also acknowledging their expressive potential, the study highlights how technical and aesthetic dimensions can mutually enrich sustainable ceramic practice.

Image 4: Example of the use of glass materials to produce aesthetic surface treatments in ceramic artworks.

6. CONCLUSION

This study successfully demonstrated the visual, chemical, and structural transformation of recycled waste glass,clear, green, and brown,when fused onto a stoneware substrate at 1200°C. The findings reveal that each glass type exhibits distinctive melting behaviours, colour responses, and surface characteristics, which are primarily influenced by their oxide compositions and thermal interaction with the ceramic body. From an artistic and environmental perspective, the study highlights the potential of recycled glass as a sustainable decorative medium in ceramic practice. The unpredictable yet aesthetically compelling outcomes underscore the creative possibilities of integrating industrial waste into fine art processes, bridging the gap between scientific material research and artistic innovation. In essence, this research contributes to the growing discourse on eco-conscious materiality, demonstrating that the transformation of discarded glass into ceramic surface decoration not only reduces environmental waste but also expands the expressive vocabulary of contemporary ceramics.

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