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Characterization of Soda Lime Silica Glass Waste as Raw Material for Making Glass Ceramics

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Abstract

The use of waste soda lime silicate glass as a raw material for glass ceramics is a subject that has been investigated for many years. This residue could be used in glass ceramics formulations as a silica source for partial or total substitution of one of the natural raw materials, commonly silica and brings the opportunity to improve sustainability. The majority of the studies in this field are related to the production of glass ceramics using different types of glasses, but this particular research is investigating the possibility of (TV screens) in order to enhance the crystallization mechanism and mechanical performance of the end product. The EDXRF analysis revealed a SiO2 content of 61.04%, alongside some other traces. Additionally, the x-ray diffraction indicated that no diffraction peak was observed in the glass powder sample, so there were no well-defined scattering planes and therefore no sharp peaks. The FTIR spectra of glass powder revealed several bands from 500 cm−1 to 4000 indicating Broad band stretching vibration of SiO4 and Si-O-Si asymmetric stretching However. The key findings are that waste glass (TV screens) can be used in the production of glass ceramics through sinter crystallization technique with technical and environmental advantages, having desirable properties required for glass ceramic tiles.

Keywords: ***characterization, making glass ceramics, soda lime silicate glass.***

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Introduction

Globally, the increase of organic and inorganic waste caused by increasing human population growth as well as their lifestyle as one of the main environmental concerns of the present time is the pollution caused by the indiscriminate disposal of materials. This problem adds up to the environmental degradation inherent in mining processes for the extraction of raw materials. Thus, the recycling of wastes that can reduce the use of mineral goods has become a very desirable solution. Heavy metals in industrial wastes are considered dangerous and anti-environment materials (Hamzawy, *et al.,* 2019; Mongi, *et al.,* 2009). Therefore, the need for stabilization/solidification of industrial wastes into useful materials or keeping it in inert condition is a great challenge (Bursi *et al*., 2017). Waste glass was attractive to either keep the industrial wastes or produce new useful materials. Cathode ray tube glass (CRTs) of television sets, which has become limited in use, contains lead oxide and is considered environmentally dangerous (Bursi *et al*., 2017). Discarded waste such as waste glasses give a negative impact on the environment. For instance, the discarded cathode ray tube (CRT) panel from the electronic component and soda-lime-silica glass from the automotive industry are polluted with heavy metals (Benzerga, *et al*., 2015). To overcome this problem, both raw materials are utilized for making valuable materials such as manufacturing stoneware tiles, production of concrete blocks, fabrication of glass–ceramics materials, and the manufacture of foam glass–ceramics (Costa, *et al*., 2020). There was a wide sector application used to insulate the materials such as the construction industry, biochemistry industry, material engineering, military security, etc. (Chen, *et al*., 2019). The production of glass and glass ceramic materials based on inorganic industrial waste generated by different industries is a promising line and has been used very successfully to precipitate crystalline phases from the glassy phase. Some of these glass ceramic materials become commercial products and found their applications in the field of abrasion resistance materials that is, industrial floor covering, wall facing abrasion resistance lining and high temperature insulators (Rawlings, *et al*., 2006). The low cost and availability of the raw materials make them very attractive economically. During recent years, considerable research work has been devoted to the recovery and safe, useful applications of waste residues originated from industries and domestic use, eg the utilization of stainless-steel slags, agricultural and domestic waste and plastics (Abis, *et al.,* 2021). The wastes from the industry contain high concentration of toxic substances, heavy metals, organic substances and soluble salts (Andreola, *et al*., 2016). Wastes processing by reduction of the noxious and toxic substances occupies central place for environment preservation as a method for environment protection. For protection of the environment against pollution by toxic materials, recycling of wastes is the only way out (Karayannis *et al*., 2017). Soda-lime silica glasses are characterized as good chemical durability, superior for optical and mechanical properties, high ultraviolet (UV) transparency and low softening point as compared to ceramic materials (Atilla, *et al*., 2013). Compared to other glass systems such as borate, tellurite, phosphate and etc., (SLS) glass has drawn great attention because of their superior glass-forming characteristic (Rawlings *et al*., 2006). Furthermore, (SLS) glass as intriguing material, many researchers due to its excellent properties such as low thermal expansion coefficient, nonlinear refractive index, fine chemical stability, high UV transparency and good durability among others find it useful in a wide variety of applications (Mugoni, *et al*., 2015). In addition, to stabilize and reduce the volume of wastes by between 20% and 97% depending on their nature (Zhu, *et al*., 2016). Industrial aluminosilicate wastes and their respective byproducts include blast furnace slag, fly ash and ashes from other industrial processes have been investigated extensively for their use as raw materials to produce glass–ceramics (Lu, *et al*., 2019) Generally, aluminosilicates waste are rich in SiO_2 and Al_2O_3, and such constitutes the framework of high strength and hardness, high chemical stability, zero or near zero coefficient of thermal expansion, zero porosity and high heat resistance to products such as glass-ceramic material (Ji, *et al*., 2015). Besides, alumino silicate waste materials also contains a few alkali/alkaline earth metal oxides that can reduce melting temperature as well as heat treatment temperature (Cao, *et al*., 2019). The increasing interest in the field of materials manufactured using industrial waste is not only attributed to an ecological interest for environmental protection, but also due to the possibility of achieving new materials (e.g., glass-ceramics) with novel properties for industrial use (Dhir, *et al*., 2018). Methods and technologies are developed which require a minimum quantity of energy and time. This waste creates serious environmental problems, mainly due to the inconsistency of waste glass streams. With increasing environmental pressure to reduce solid waste and to recycle as much as possible, there is a significant interest in finding applications for the development of value-added products.

Soda-lime silica (SLS) glass as common type of glass possesses excellent properties because they easily tempered to increase strength, they are chemically resistant and making them potential candidate for applications in food storage and beverages (Aliyu, 2019). They have low melting temperature and easier to manipulate when in molten state and such provides window for formation of a wide range of shapes for numerous applications, and such shapes can be subjected to heat treatment for easy transformation into glass-ceramics via sinter crystallization process (Aliyu, 2020). In addition, soda-lime silica glass has high optical transmission and making it relevant for applications needing transparency such as containers and windows (Salisu, *et al.,* 2024). Soda-lime silica glasses are ideal for windows and windowpanes due to their high optical transmission, also, they are used as containers such as drinking glasses, serving dishes, bottles, jugs and jars among others (Atilla, *et al*., 2013). According to Udi (2023), in terms of mechanical properties, the isotropic of soda-lime silica glasses is nearly perfectly elastic and its failure to yield plastically had made it exhibits brittle behaviour. Glasses are generally stronger in compression due to closure of void or microcracks when subjected to compression but becomes weaker in tension as a result of opening of imperfections when subjected to tension (Udi *et al.,* 2023). Therefore, The main objective of this work is to characterize waste soda lime silicate glass based on oxides constituents, crystalline structure, as well as bond and functional group using XRF, XRD and FTIR respectively, aiming for a notable application as a silica source for the production of glass ceramics.

Methodology

This section with the materials and methods used for sample collection, preparation and for the analysis of the mineral compositions. The samples collected during this study were analyzed to obtain the characteristics features, crystalline structures and functional group.

Experimental Procedure

This work dealt with the characterization of waste glass powders via the study of oxides compositions using XRF, crystalline phases through XRD, as well as bond and functional groups via the FTIR. After collection of samples, sorting, crushing, grinding and milling of waste glass sample to the required particle size of 75 μm was carried out. The oxides composition analysis was performed using Energy Dispersive X-ray fluorescence techniques (Thermo scientific EDXRF QUANT'X 9952120) in the semi-quantitative mode to determine the various oxides present in the sample, X-ray diffraction Rigaku Corporation Japan with Cu Kα (λ=1.5418 Å radiation operated at 30 kV and 15 mA was carried out on the powdered glass sample to help in studying the crystalline phases precipitated in the glass matrix. The glass powdered sample was scanned from 5-70°2θ with a step size of 0.01 to 100°/min. as counting time for every step. The Goniometer is of Bragg-Brentan geometry with 150 mm radius, and has a measurement range (2θ) of 2° – 145° was used. Furthermore, the FITR spectra was obtained using [PerkinElmer Spectrum

100 FTIR analyzer] to study the bond and functional group.

Results and Discussion

Chemical Analysis (EDXRF)

The oxides composition in percent (wt %) of the glass sample is presented in Table I. The predominant presence of SiO_2 as the forming agent of the glass network can be observed, while Na_2O and CaO are used in glass as modifying oxides. The importance of oxides observed in Table I, highlighting their influence on properties of analyzed glass powders was commented. A great potential for recycling soda-lime silica waste glass has a large amount of silica (SiO_2) 60- 70 wt%, which is responsible for forming the glass network. Modifying oxides such as Na_2O, MgO, Al_2O_3, CaO, K_2O, and SrO with weight concentrations of 13.25wt%, 2.96wt%, 2.1386wt%, 2.8141wt%, and 8.462wt% respectively as well as Al_2O_3 (2.53 wt%) as stabilizing agent were found in the waste glass powdered sample. The obtained result is in line with the findings of Diaz *et al*., (2015), who conducted a study on the Glass-ceramic, using (TV screen) and galvanic wastes as raw materials and observed that oxides as mentioned above are present in the waste glass powders as well as the silica content of 54.034% was present. However, the XRF result of the waste glass, as given in Table 1, shows the typical high content of silica SiO_2 (61.04wt %).

Table 1: X-ray fluorescence analysis of waste glass (TV screen] powders

Oxides	Concentration (%)
SiO_2	61.04
Na_2O	13.25
SrO	8.462
Al_2O_3	2.53
MgO	2.96
CaO	2.1386
K_2O	2.8141
BaO	1.9115

PbO	2.499
Traces	2.379%

X-ray Diffraction Measurements (XRD)

X-ray diffraction, the diffractogram of the glass powders presented in Fig. 1 shows the absence of crystalline phases; this spectrum represents a typical amorphous band derived from the presence of silica in the sample. This features glass powder as an amorphous solid without symmetry and/or long rang periodicity in the atomic arrangement. The X-ray diffraction (XRD) pattern of a material provides information about its crystalline structure. If the XRD pattern of waste glass powder does not show any specific shape or diffraction peaks, it typically indicates that the material is amorphous, meaning it lacks a regular, repeating crystalline structure. The absence of specific peaks or shapes in the XRD pattern is expected for amorphous materials like glass. If there are impurities or crystalline phases present in the waste glass powder, they might contribute to the XRD pattern, but the main glass component will likely dominate with its amorphous characteristics. As it's obvious, that the XRD pattern has no sharp peak therefore confirms that the material is glassy. It is mentioned in various literatures that the XRD pattern of the glassy material is domed shape with no specific peaks. The obtained result aligns with the characterization carried out by previous studies by Alizadeh & Soleimani (2019), who confirmed that the dome shape glass samples with no specific peak or shape represents a glassy material. However, Dahal, (2023) explained that a glassy material lacks long-ranged order, therefore, no well-defined scattering planes exist and therefore no sharp peak is observed and no crystalline phases are detected dispersed in the matrix of glass.

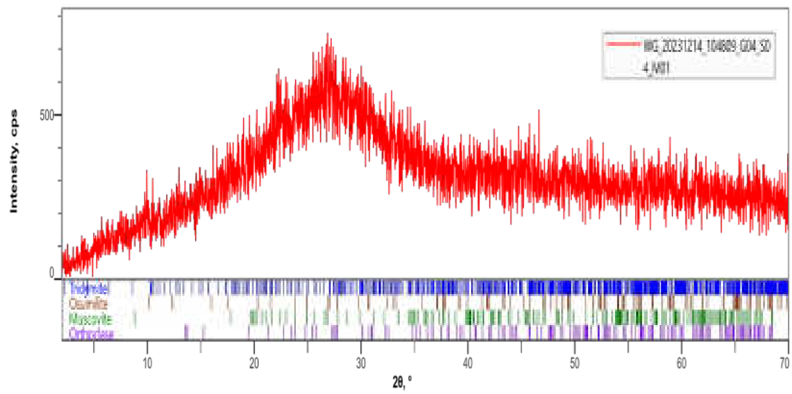

Fig. 1: X-ray diffraction of glass powders

Infrared Absorption Measurements (FTIR)

Infrared absorption spectra of the prepared glass powder sample as shown in Figures (2) from which it is observed that the infrared absorption spectra of the glass powder sample obtained from Television screen (T.V screen) resemble the familiar spectrum of commercial soda lime silica glass. The IR absorption spectrum consists of the following main bands: A main strong band in this region at about 760.37 cm^{-1} indicate the Si-O in the tetrahedron, subsequently, the main strong absorption band is preceded by another band at about 969.11 cm^{-1} indicate the Si-O asymmetric stretching. The relatively high intensity (86.94) suggests a significant amount of Si-O bonds in the sample, pointing towards a silicate-based composition.

The realization and interpretation of the IR absorption spectra have been carried out in agreement with the concept adopted by (Kumar, *et al*., 2010) about independent vibrations of different groups. Also, it is born in mind the detailed published infrared spectra of multi component silicate glasses (Cui, *et al.,* 2015). The structure of silicate glasses is originally similar to silicate crystals and consist of SiO_4 tetrahedra but in glasses the groups are in non-periodic arrangement (Kumar, *et al*., 2010). In the glass, the SiO_4 tetrahedra are linked at the vertices to form a network, while the various modifiers such as alkali and alkaline earth ions occupy interstices or holes within the networks. Some oxygen atoms are bonded to only one silicon and are called nonbridging oxygen atoms (NBOs). (Kumar, *et al.*, 2010; Kaur, *et al.*, 2012; Sasmal *et al.*, 2014)

All the identified infrared absorption bands exhibit similarity to the characteristic bands typically manifested in silicate glasses and crystalline structures, with slight deviations attributable to the presence of additional constituent elements. Collectively, these bands predominantly signify the silicate framework.

Table 2: Represents the FTIR spectra of waste soda lime silicate glass (TV screen)

Wavelength peak (cm^{-1})	Possible functional group	*References*
1401	Broad band indicates stretching vibration of SiO4	(Kumar, *et al.*, 2010; Kaur, *et al.*, 2012; Sasmal *et al.*, 2014)
760.37	Si-O in the tetrahedron	(Kumar, *et al.*, 2010; Kaur, *et al.* 2012)
969.11	Si-O-Si asymmetric stretching	*(Cui,* et al., *2015)*

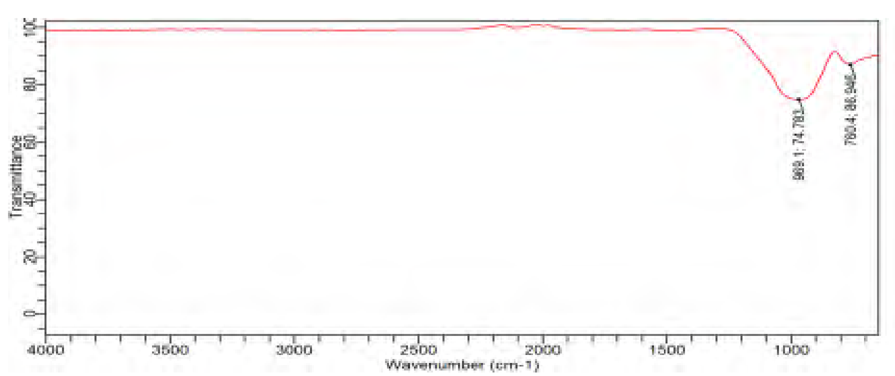

Fig. 2: FT-IR of waste glass powders

Conclusion

The use of natural resources as raw materials in production processes is currently being evaluated for the negative impact on the environment associated with the depletion of energy resources and environmental degradation aspects that are not sustainable. Waste glass television screen (TV screens) are not being used in the recycling streams and are disposed of in uncontrolled landfills generating high environmental impact. There was significant interest in finding applications for the development of value-added products. Therefore, the goal of the present investigation is to characterized waste glass television screen (TV screens) through refining and chemical characterization, morphological observation and fictional group analyses aiming for noble applications mainly as a raw material for making glass ceramics. The main conclusions are: the refinement of the fine glass powders generated particles of 75 μm; After XRD and XRF analyses, the results confirmed that the material was a glassy material from soda-lime glass with the following oxides presence such as SiO_2, Na_2O, CaO and Al_2O_3, showing SiO_2 as dominant oxide present. The findings revealed that waste glass can replace naturally occurring silica-based materials that have technical and environmental advantages having the desirable properties required for commercial glass ceramics production.

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