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Comparative analysis of selected silica – rich solid wastes for potential application as silica source in silica based ceramic products

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Abstract

The goal of this research is to characterize selected silica-rich solid wastes for potential use as silica source. The two prominent wastes chosen for this study are waste container soda-lime glasses and rice husks (agro-waste), both of which are known to be silica-rich wastes. Rice husk ashes (RHAs) were produced by thermally treating rice husks, while waste container soda-lime-silica glasses (WSLSG) were crushed and milled to produce glass powder. EDXRF was used to examine the chemical compositions, while XRD was used to determine the mineralogical composition. SEM was used to examine the morphology of these wastes; TGA/DTA was used to evaluate their thermal behavior; and FTIR was used to examine their molecular bonding. The EDXRF results revealed that both RHAs and WSLSG contain similar oxides but have a higher SiO2 content of 79.7 and 69.4 wt. percent respectively. The XRD results show that both RHAs and WSLSG have a typical amorphous SiO2 band; the FTIR results show that both RHAs and WSLSG have similar Si - O- Si (SiO2) bonding at intense wavelengths of 1069.7 cm-1 and 939.3 cm-1, respectively, and weak wavelengths of 797.7 cm-1 and 767.8 cm-1, respectively. SEM microstructure analysis revealed that both RHAs and WSLSG have similar irregular geometry, but RHAs have fewer pores. According to the TGA/DTA results, both WSLSG and RHAs have better thermal stability with temperature.

Keywords: Rice husk ashes; Waste soda-lime glasses; Waste recycling; Silica – rich solid wastes

1. Introduction

Waste recycling and the valorization of by-products from municipal, industrial, and agricultural processes has recently become a major global concern. In response to environmental regulations aimed at reducing the amount of waste sent to landfills, the development of recycling techniques capable of incorporating these wastes into new marketable ceramic products has skyrocketed [1 - 2]. This will save money, reduce energy consumption, and help with solid waste management.

According to the Food and Agriculture Organization [3], the world's rice production is over 528 million tons per year, yielding approximately 145 million tons of husks as waste material sent to landfills, causing environmental pollution. When rice husks are burned as fuel to generate energy, residual ashes known as rice husk ashes (RHAs) are produced as a waste material that is high in silica. Several studies have been conducted over the years in which RHAs have been used as a cost-effective alternative to silica (Quartz) in the processing of silica-based ceramic products such as silica gel [4], silicon nitride [5], silicon carbide [6], and porcelains [7].

Glass, on the other hand, is amorphous, inert, and non-porous. Glass is a popular storage and packaging material. The global annual production of glass is estimated to be over 89.4 million tons in 2007, and has increased dramatically over the decades due to increases in industrialization, living standards, and demand [8]. However, due to a lack of

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information from various countries, there is no clear information on the amount of waste glasses generated globally [8]. However, several million tons of waste glasses of various colors ranging from clear to green to amber are expected to be sent to landfills worldwide each year. Glass is completely recyclable, which saves both natural resources and the environment. Waste glasses have recently been recycled and used in a variety of applications, including as a flux replacement in ceramic products [9], a partial substitute for quartz [10], pozzolanic material [11],, and foam glass [12], to name a few.

Despite the vast utilization and relevance of these prominent selected wastes (RHAs and WSLSG) as silica source in most silica based ceramic products, little or no work has been conducted to study these wastes in order to fully determine the reason for being good economic alternative source to processed silica in most silica-based ceramic products; therefore, the need for this present research.

2. Material and methods

2.1. Materials

The two selected silica – rich solid wastes used in this present study are rice husks (RHs) and waste container soda-lime-silica glass (WSLSG).

The rice husks used in this study came from a rice milling plant in Igbemo-Ekiti, Ekiti State (7.6838^{o} N, 5.3812^{o} E), South-West Nigeria, while the waste container glasses (mixes of clear, green, and amber color) came from municipal solid wastes (MSW). To remove dirt and unwanted residues from the rice husks, they were thoroughly rinsed with distilled water. The thoroughly rinsed rice husks were then air dried at room temperature for 24 hours before being oven dried at 110^{o}C for 24 hours in an electric oven. The dried rice husks were then placed inside a crucible and burned in a muffle furnace. The rice husks were gradually heated from room temperature to 700oC and maintained for 1 hour for soaking at a heating rate of 10oC per minute before being removed from the muffle furnace after the heating schedule was completed. Rice husk ashes (RHAs) were obtained and sieved through a 75m sieve to obtain a fine RHAs powder. The waste container soda-lime glasses obtained from MSW, on the other hand, were a mix of clear, green, and amber colors. Prior to crushing, these waste glasses were thoroughly washed with water and allowed to dry properly in the air for 24 hours. The dried waste glasses were then fed into the crusher, where they were crushed into small particles. The crushed waste container glasses were then fed into a ball mill that rotated at 40 rpm for two days to produce fine glass powders that were sieved through a 75m sieve.

2.2. Analyses

Various analyses were performed using standard procedures to characterize and compare the obtained rice husk ashes (RHAs) and recycled fine powdered waste glasses (WSLSG). To quantify the concentrations of SiO2 and other oxides present, the chemical composition of the RHAs and WSLSG was examined using a high performance Energy Dispersive X-ray Fluorescence (EDXRF) XSUPREME 8000. X-ray diffractometer phase identifications were determined using BRUKER AXS with D8 Advanced diffractometer Cu K radiation XRD in the range of 2 tetha angle from 5 to 70 scanning range. The morphology features were examined using gold coated sample by high performance Phenom Prox scanning electron microscope (SEM) in order to assess their microstructure characteristics. Identification of molecular bonding of the RHAs and WSLSG were evaluated using Fourier-transform infrared spectroscopy (spectrum 100 FT-IR Spectrometer, Perkin Elmer). The thermal behavior of the RHAs and WSLSG were evaluated using Thermo gravimetric and differential thermal analysis (TGA/DTA) in a simultaneous analyzer (Perkin Elmer – TGA 4000) heated from 45^{o}C to 950^{o}C at a heating rate of 10^{o}C/min.

3. Results and discussion

Table 1 shows the chemical compositions of rice husk ashes (RHAs) and recycled fine powdered waste glasses (WSLSG) as determined by EDXRF in the form of stable oxides. Both wastes have a similar chemical composition, with silica being the most abundant component (SiO2). However, RHAs have the highest silica content of 79.7 wt. percent, while WSLSG has 69.4 wt. percent SiO2, which is less than the amount of SiO2 in synthetic silica as determined by [13]. This indicates that both wastes contain enough silica to be used as silica sources in the production of silica based ceramic products. Figures 1(a) and (b) show the X-ray diffraction (XRD) spectrum results for RHAs and WSLSG, respectively. Both wastes had somewhat similar diffraction patterns, with their diffractogram indicating the presence of silica in the amorphous form due to the dominant one broad peak of a typical amorphous band between 22^{o} - 27^{o}, which is consistent with [1] and [14] as stated by [13], processed or synthetic silica is made up of the crystalline phase of SiO_2. According to [15 - 17], crystalline SiO2 is the most stable form, while amorphous silica is the most soluble. As a result, RHAs and WSLSG containing high SiO_2 in amorphous form are regarded as new economically worthwhile raw materials for silica based ceramic products

Table 1 Chemical composition of the RHAs and WSLSG by EDXRF

	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	P_2O_5	Fe_2O_3	Cr_2O_3	Mn_2O_3	TiO_2
RHAs	80.0	1.48	1.69	3.12	0.08	2.58	9.49	1.09	0.00	0.14	0.09
WSLSG	69.4	5.03	15.03	0.55	7.22	0.65	0.09	0.71	0.13	0.02	0.65

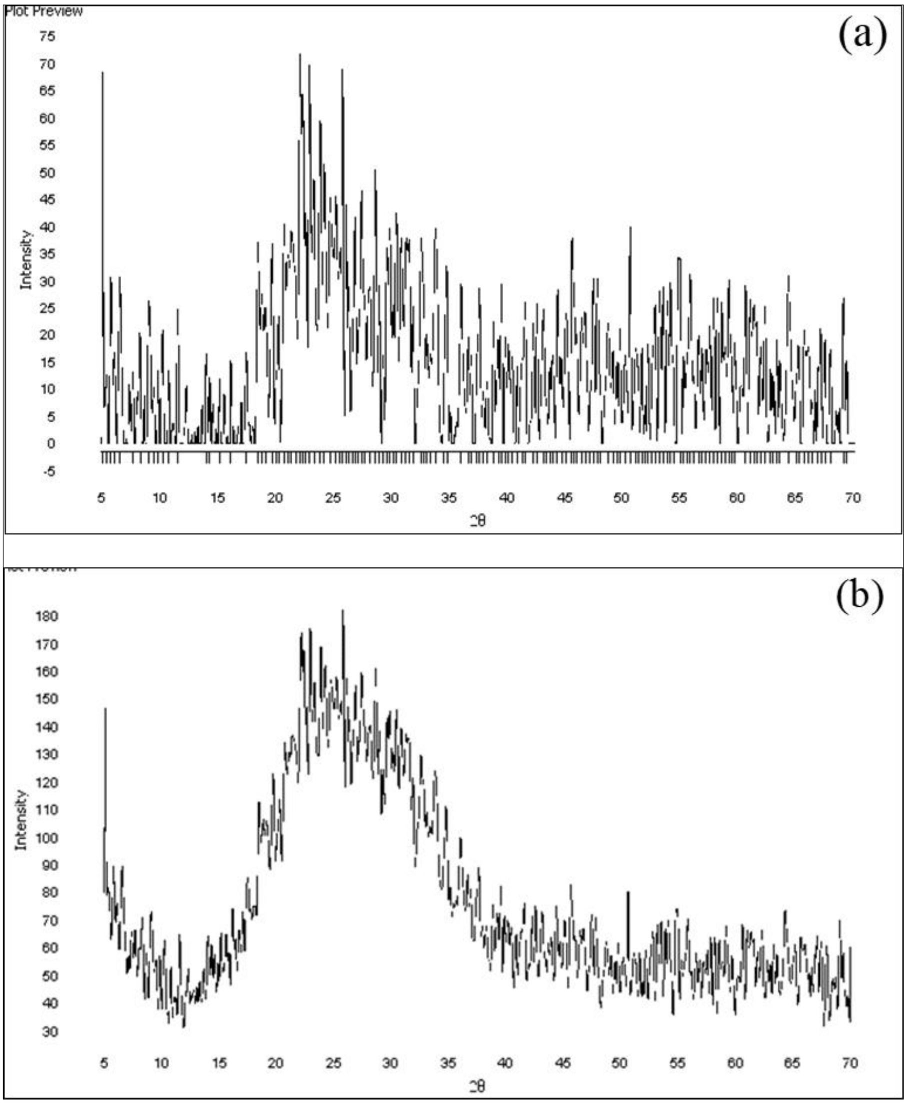

Figure 1 X-ray diffraction pattern of (a) Rice husk ashes (RHAs) and (b) waste soda-lime glasses (WSLSG)

Figures 2 (a) and (b) show the morphology features of RHAs and WSLSGs based on the SE images. Figure 2(b) shows the morphology characteristics of WSLSG, which has irregular geometry with the presence of coarse granular particles, indicating the morphology of a typical irregular geometry of silica. However, in Figure 2(a), which depicts the morphology features of RHAs, it can be seen that, while the particles have irregular geometry, the coarse granular features have not fully developed as seen in WSLSG (Fig. 2b), which could be attributed to the temperature (700°C) at which it was thermally treated. Coarse granular particles of RHAs are known to be fully developed at more elevated temperature according to Azmi *et al.* [14].

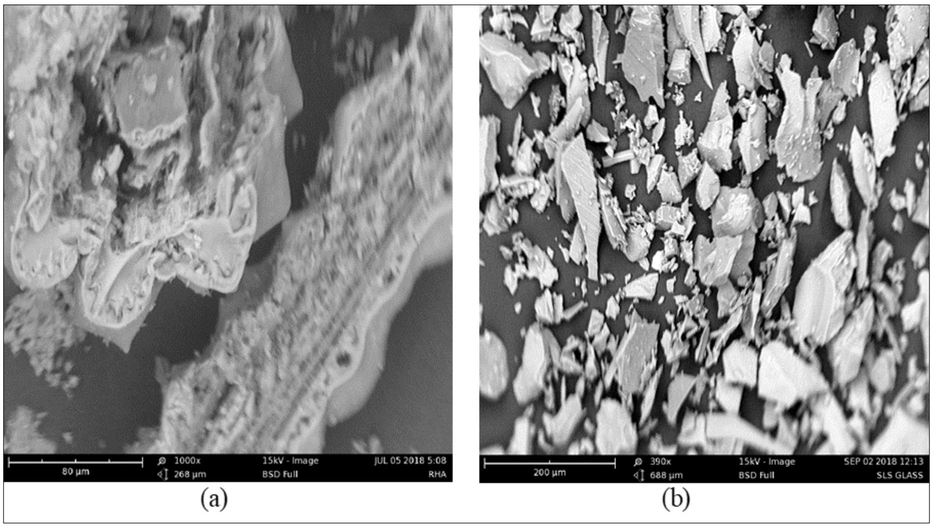

Figure 2 SE images of (a) rice husk ashes (RHAs) and (b) waste soda-lime glasses (WSLSG)

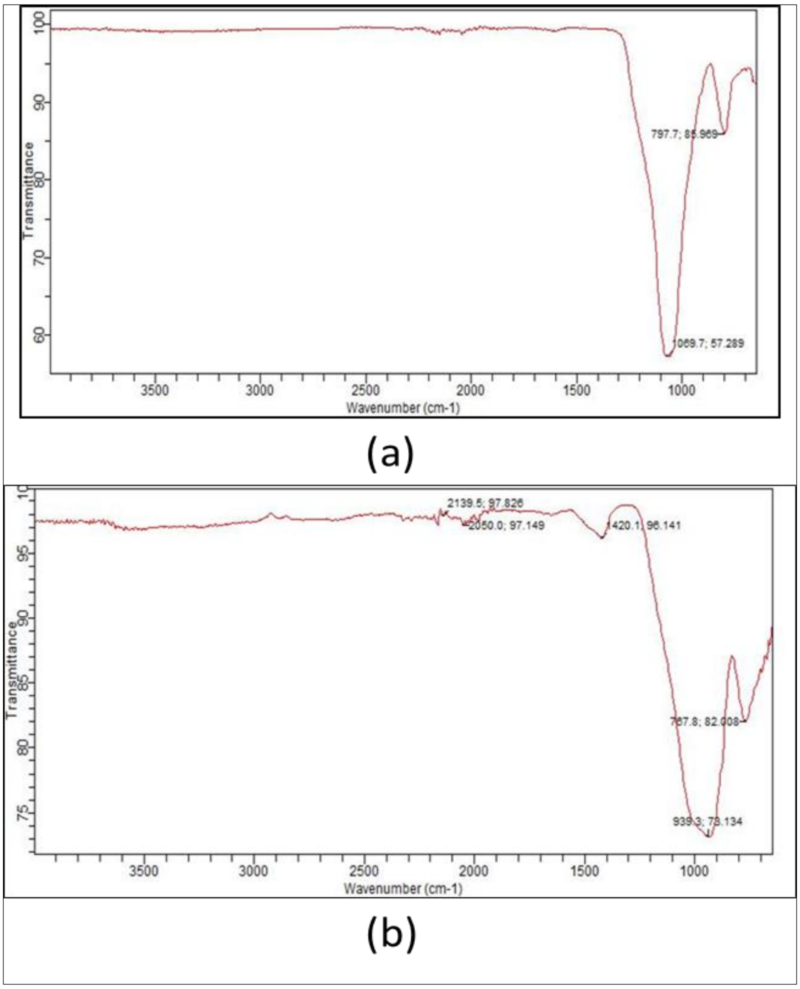

Figure 3 FTIR spectra of (a) rice husk ashes (RHAs) and (b) waste soda-lime glass (WSLSG)

The FTIR spectra were similar, as shown in Figures 3 (a) and (b), with two prominent transmittance peaks at specific wavenumbers. RHA transmittance peaks were observed at 1069.7 cm-1 and 797.7 cm-1, respectively, while WSLSG transmittance peaks were recorded at 939.3 cm-1 and 767.8 cm-1. However, additional weak peaks at 1420 cm-1, 2050 cm-1, and 2139.5 cm-1 were detected in WSLSG. The predominant intensity peaks observed in both RHAs and WSLSG at wavenumber ranges of 900 - 1100 cm-1 may be attributed to Si - O - Si asymmetric bending and stretching vibration bonds, indicating the presence of siloxane structural bonding, as reported by [16]. This is in similarity with what was observed for synthetic silica reported by [14]. Weak peaks recorded at wavenumber range 700 – 800 cm^{-1} in the spectra of both RHAs and WSLSG can be attributed to stretching of symmetric Si – O bond referred to as Silanol as reported by [18]. The additional weak peak observed in WSLSG at 1420 cm^{-1} and wavenumber range 2000 – 2500 cm^{-1} might be due to absorption and disturbed silanols respectively.

4. Conclusion

This work has dealt with analysis of two major selected solid wastes which are rice husks and waste soda-lime glass through chemical characterization, molecular bonding, thermogravimetric and morphological analyses for potential application in silica based ceramic products and thus contributing to environment by reducing the amount of these wastes sent to landfill.

The results showed that:

- Both rice husk ashes (RHAs) and waste soda-lime glass (WSLSG) consist of silica content which are high enough to justify their use as silica source in synthesis of sodium silicate as shown by the EDXRF result
- The XRD results showed that both RHAs and WSLSG displayed high amorphous silica broad peaks typical of amorphous silica band and which are known to be soluble unlike crystalline silica as supported by literature; making them valuable source of silica for sodium silicate production.
- The FTIR results showed that both RHAs and WSLSG possessed typical Si – O – Si bonding and which justify their use as silica source in sodium silicate production while thermogravimetric results showed spots where weight loss, carbonates decomposition and quartz transformation occurred.

The scanning electron microscopy (SEM) revealed that both RHAs and WSLSG displayed irregular geometry with the presence of coarse granular particles indicating the morphology of a typical irregular geometry of silica. However, the coarse granular features are yet to fully develop in RHAs which is attributable to the level of phase crystallinity which is a function of the burning temperature of the RHAs.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no conflict of interest.

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