AGRO-WASTE ASHES AS A FEEDER FOR THE SYNTHESIS OF SIO_2 NANOPARTICLES FOR ROAD CONSTRUCTION

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ABSTRACT

The global rapid population growth is leading to accelerated food production thus accelerating the generation of agricultural wastes (AWs). Among the AWs management strategies is the valorisation of the AWs into useful products such as the production of silica nanoparticles (SNPs) which are useful in the road construction sector. Production of useful SNPs from AWs for the road construction industry is considered sustainable road construction, as not only does it reduces the carbon dioxide footprint from similar materials such as cement, but it is also cheap and readily available to low-income countries such as Kenya and Zambia. SNPs are of great importance in the production of high-strength materials such as stabilized soil and asphalt of significant strength than the conventional stabilised soil/asphalt with ordinary Portland cement. In this review, recent progress on AWs corresponding ashes (AWAs) with significant silica is studied. The production of SNPs from this AWAs is examined in detail concerning their synthesis methods for high purity SNPs, structure, phase, morphology, sizes, and their application in soil and asphalt stabilisation in road construction. The use of AWs to produce SNPs for use in the stabilisation of soils, bitumen, and asphalt for roads construction is promising, however, there is a need for further research on the large-scale production of SNPs from AWAs.

Keywords: biomass, construction, nanomaterials, nanotechnology, ordinary Portland cement (OPC), silica nanoparticles.

1 INTRODUCTION

Agricultural wastes are mainly of four types as shown in Fig. 1. They are composed of crop, food, industrial processing, and livestock wastes. They are generated after the useful part of the crop is extracted or while rearing livestock. Just as any other wastes, AWs need to be managed properly for a hygienic environment through different waste management strategies. These strategies include utilising the AWs in the production of novel products ass value-addition to the agricultural economy. These AWs are burned to produce AWs Ashes (AWAs).

Some of the novel products that can be produced from AWAs are SNPs. SNPs are either produced by bottom-up or up-bottom methods using minerals that are non-renewable such as silica sand. There is a need to minimize the use of non-renewable sources to produce SNPs. This has led to research on using AWAs to produce SNPs that are considered as green. It results in AWs management while enhancing value addition in agriculture. These SNPs can used as pozzolanic additives in civil engineering projects for strengthening concrete, and the production of plastics and rubber materials. This results in sustainable construction.

In this review, recent progress on AWAs with significant silica is studied. The production of SNPs from AWAs is examined in detail about their synthesis methods for high purity SNPs, sizes, and their application in soil, bitumen, and asphalt stabilisation in road construction sector.

2 AGRO-WASTES CONTAINING SILICA

Table 1 shows some of the AWAs containing silica as characterised by x-ray fluorescence spectroscopy (XRF) from recent studies. Rice straw and husk ashes as crop waste and

WIT Transactions on Ecology and the Environment, Vol 257, © 2022 WIT Press
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/WMEI220051

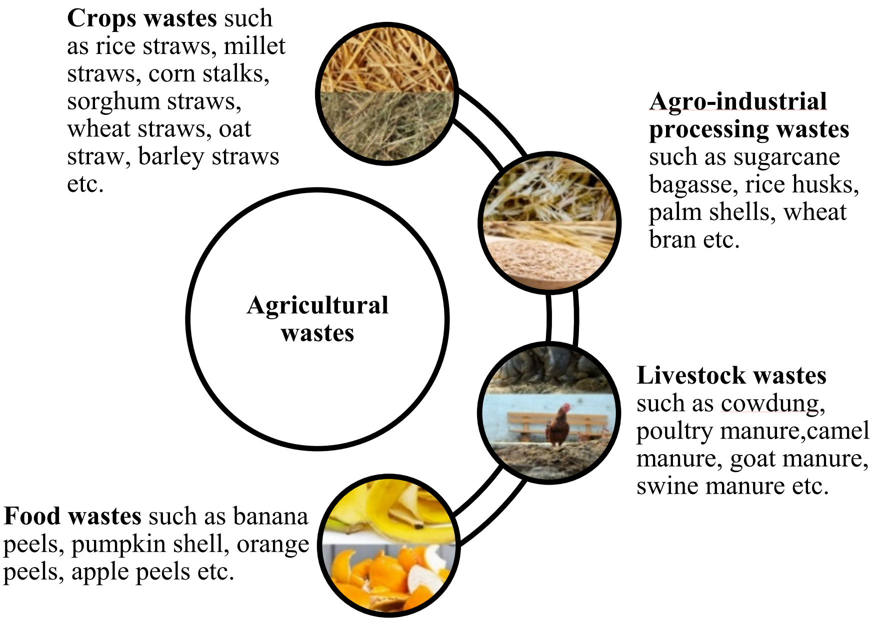

Figure 1: Types of agricultural wastes.

Table 1: Agricultural wastes ashes containing silica as characterised by x-ray fluorescence spectroscopy (XRF) from different studies.

Biomass ash	Silica (SiO_2) (%)	Reference
Rice husk ash	72.2–99.50	[1]–[6]
Areca sheath ash	78.00	[7]
Sugar cane bagasse ash	40.46–98.40	[8]–[16]
Palm leaf ash	53.11–82.15	[17], [18]
Corn cob ash	64.80	[19]
Barley straw ash	55.00–61.75	[20], [21]
Bamboo leaf ash	72.81	[22]
Millet husk ash	69.40	[23]
Wheat straw ash	67.83	[23]
Wood ash	7.75–68.51	[24]–[27]
Sorghum husk ash	70.48	[28]
Paddy waste ash	84.78	[29]
Ficus leaf ash	81.45	[30]
Palm oil fuel ash	61.68	[31]
Sunflower ash	50.36	[32]
Anacardium ash	65.02	[33]
Cowdung ash	57.33–61.00	[34], [35]

industrial processing waste respectively are the main studied AWAs as they contain a lot of silica. Cow dung ash and areca sheath ash represents the livestock and food wastes respectively. Silica is one of the main components of any material to be characterised as a pozzolanic material in road construction or any general construction works. Alongside silica, are the alumina and ferrous oxides.

3 SYNTHESIS OF SILICA NANOPARTICLES FROM AGRICULTURAL WASTES ASHES

Table 2 shows the studies that have been undertaken on the production of SNPs from the AWAs. RHA is the main studied material among the AWAs. Several reviews have been done on the production of SNPs from AWAs [36], [37], however, most of the reviews focus only on single crop residues. Agricultural wastes consist also of food and livestock wastes. Some studies have also focused on specific crops such as rice husk ash and straws ashes to produce novel products [38], [39] This review brings together all together these studies to make some general conclusions from the existing data.

The sol-gel method is the most preferred synthesis method. Few studies exist on other methods such as sonochemistry. This is the case because the sol-gel process involves producing solid materials from small molecules [49]. UV-visible spectroscopy (UV-Vis), FE-SEM energy-dispersive x-ray (EDX), x-ray diffraction (XRD), and FTIR, are some of the main spectroscopy techniques used for characterisation of the produced SNPs. Most of the SNPs produced from the AWAs are amorphous.

4 APPLICATION OF AMORPHOUS SILICA NANOPARTICLES

This research reviews the use of amorphous SNPs in road construction, especially on soil stabilisation, and the use of SNPs additives in bitumen or asphalt as detailed in Table 3. Few studies are published on the use of SNPs for soil stabilisation for road construction [50]. In addition, studies on the use of SNPs as additives in bitumen and asphalt exists though limited [51].

The review indicates that residual soil can be improved by over 200% in terms of compressive strength when 15 nm-SNPs are added [50]. The penetration grade and viscosity grade of bitumen and asphalt are also improved when SNPs are used. This is mainly on aging and fatigue resistance as detailed in Table 3. Bitumen and asphalt are stabilised against rutting, cracking, and temperature susceptibility. The elasticity of bitumen and asphalt increases, with more resistance against the flowing, and decreased the fatigue life.

5 CONCLUSION

In the current research, recent progress on AWAs with significant silica has been listed. RHA and SCBA are the main AWAs being studied with high silica content. The production of SNPs from this AWAs is examined in detail with regard to the synthesis methods for high purity silica nanoparticles, characterisation, and its application in soil and asphalt stabilisation in road construction. The study shows that the sol-gel method is the most preferred synthesis method for SNPs from AWAs. UV-Vis, FTIR, FESEM, EDX, and XRD are some of the main techniques used for the characterisation of the produced SNPs. The results show that most of the SNPs produced from the AWAs are amorphous with sizes ranging from 5 to 75 nm. Though there exist latest few studies on the application of amorphous SNPs in road construction, they are promising with regard to improving the compressive strength of soil and the performance of bitumen and asphalt thus longer life span.

Table 2: Production of SNPs from some agro wastes.

Agro waste ash	Synthesis method	Characterisation and analysis	Characteristics	Ref.
Rice husk ash (RHA)	The sol-gel technique.	Ultraviolet-visible spectroscopy (UV-Vis), Fourier transform infrared (FTIR), field emission scanning electron microscope (FE-SEM), EDX, and XRD were used in this study.	Amorphous SNPs with sizes of 15–20 nm.	[40]
Palm shell ash (PSA)	The modified sol-gel technique.	XRD, SEM, EDX, FTIR.	Amorphous SNPs with sizes ranging from 50 nm to 98 nm. The surface area was 438 m^2 g^{-1}.	[41]
Sugarcane bagasse ash (SCBA)	The Sol-gel polymeric method	X-ray fluorescence spectroscopy (XRF), SEM equipped with EDX and TEM were employed.	SNPs, are obtained as a nanostructured powder of about 10 nm in diameter with over 95% of purity.	[42]
Bamboo leaves ash	The Sol-gel method	UV-Vis and FTIR.	The FTIR spectrum confirms the presence of SNPs within the functional groups as shown in Fig. 2.	[43]
Banana peels ash	The sol-gel method	FTIR instrument.	The FTIR spectrum had functional groups ranging from 400 cm^{-1}. to 4,000 cm^{-1}. Confirming the presence of SNPs.	[44]
Rice husk	The chemical method	XRD, FE-SEM, EDAX, and TEM.	The SNPs obtained were between 3 nm to 10 nm and with the highest surface area of about $247m^2/g^{-1}$).	[45]
Rice husk ash	The sonochemical process	FE-SEM, EDX, TEM and FTIR.	SNPs obtained had sizes from 5 nm to 40 nm and the surface area from 176 m^2g^{-1} to 226 m^2g^{-1}.	[46]
RHA, BLA, SCBA, and groundnut shell ashes	The dissolution and precipitation process	FT-IR, XRD, and SEM-EDAX.	SNPs produced had a diameter ranging from 20 nm to 40 nm.	[47]

Table 3: Production of SNPs from some agricultural wastes.

Material	Size of NPS	Tests done	Performance	Ref.
Residual soil	15 nm and 80 nm	Atterberg limits, hydraulic conductivity, pH value, unconfined compressive strength (UCS) tests	The maximum strength improved from 550kPa to more than 1600kPa when SNPs of 15 nm were added to 8% cement	[50]
Bitumen-64-22 penetration grade (PG)	12 nm	Aging index, dynamic shear characterization, and direct tension test (DTT)	The addition of SNPs improved the bitumen in terms of rutting, cracking, and temperature susceptibility	[52]
Asphalt binder (PG 64–22)	12 nm	Accelerated aging of asphalt binder (AAAB), and DTT among other tests	SNPs improved the flowing and elasticity properties of asphalt	[53], [54]
60/70 PG asphalt binder	20–40 nm, 175–225 m^2/g BET surface area	Rotational viscosity test (RVT), frequency sweep (FS) test, multiple stress creep recovery (MSCR) test, linear amplitude sweep (LAS) test, four-point bending beam fatigue test (FBBF), bending beam rheometer (BBR) test	The addition of SNPs increased the elasticity of binders, with more resistance against the flowing, and decreased the fatigue life	[55]
No. 90 base asphalt binder	About 30 nm	BBR test, FS test, LAS test, MSCR test, temperature sweep (TS) test, rheological property tests, physical property tests, microstructure tests	The addition of SNPs, presented the greatest fatigue life and anti-crack property	[56]
Viscosity-graded (VG) asphalt binders	Under 200 nm	MSCR	SNPs addition in viscosity graded asphalts enhances its resistance to permanent deformation and fatigue	[57]
35/50 PG	70 nm	Fatigue, deformation, stiffness tests	SNPs modification presented the best global performance	[58]
60/70 PG bitumen	20–30 nm, 180–600 m^2/g surface area	Simulation of aging asphalt binders, FS test, fatigue testing	SNPs-modified binders had a better performance of fatigue behaviour compared to the control binders	[59]
Different asphalt models	7.5 nm	Molecular dynamics (MD) simulations	SNPs reduce erosion from chlorides	[60]
85/100 PG bitumen	20–30 nm	Four-point bending beam test	Samples containing 5% SNPs had a higher rate of self-healing	[61]
PG bitumen 60/70 and 85/100	20–30 nm	Compressive and tensile strength tests, modified Lottman indirect tension test	SNPs resulted in a significant increase in compressive strength	[62]
PG 64-22 bitumen	20–30 nm	MSCR test	The SNPs improved bitumen resistance to rutting	[63]
In-Organic silt	5 to 50 nm	California bearing ratio (CBR)	The SNPs lead to improvement of bearing strength	[64]
Loessial sediments	20–30 nm	Electrokinetic method	The SNPs performed more than the conventional lime by 2%	[65]

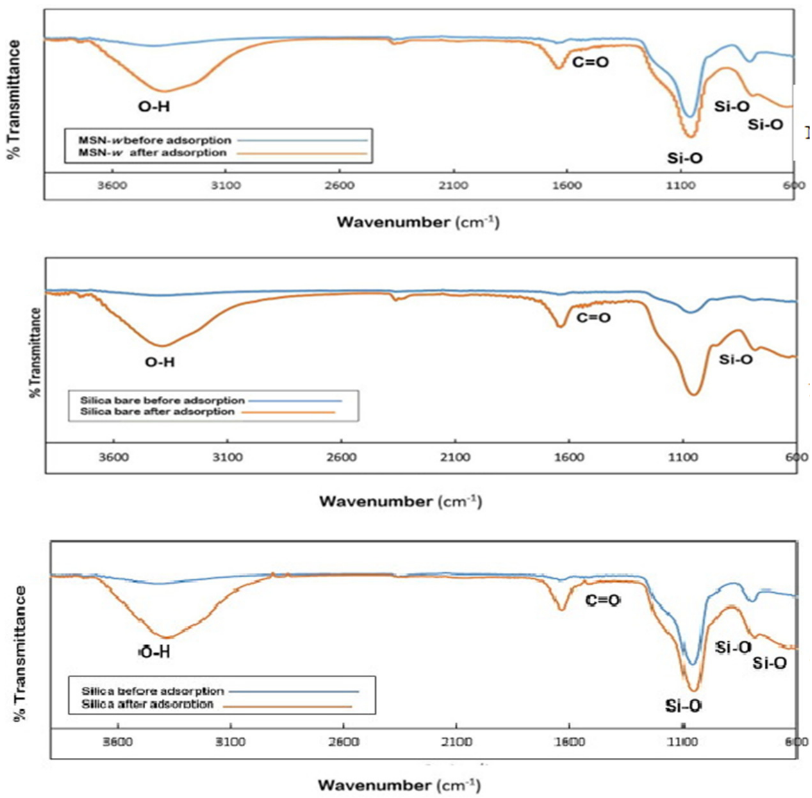

Figure 2: The FTIR spectrums of produced SNPs [43], [48].

6 CHALLENGES, OPPORTUNITIES, AND FUTURE RESEARCH

The use of AWAs to produce SNPs for use in the roads construction industry is promising though there is a need for further research on large-scale production. Large quantities of AWAs would need to be able to manufacture enough SNPs. Agricultural produce being perennial, there can be produced throughout the year. There is also need to undertake pilot real projects on the use of SNPs and its economic life cycle evaluated.

ACKNOWLEDGEMENTS

We appreciate the financial support of the Copperbelt University, Africa Center of Excellence for Sustainable Mining (CBU-ACESM) to work on this paper and attend the 11th ICWMEEISD Conference.

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