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Synthesis and characterization of SnO₂ nanofiller from recycled expanded polystyrene

Olusola Olaitan Ayeleru^{a*}, Sisanda Dlova^a, Freeman Ntuli^b, Williams Kehinde Kupolati^c,
Peter Apata Olubambi^a

^aCentre for Nanoengineering and Tribocorrosion, University of Johannesburg, Johannesburg 2028, South Africa

^bChemical, Materials and Metallurgical Engineering Department, Botswana International University of Science and Technology,
Private Mail Bag 16, Palapye, Botswana

^cDepartment of Civil Engineering, Tshwane University of Technology, Pretoria
0001, South Africa

Abstract

Polymer waste that has been viewed as a major threat to our environment is currently gaining attention as valuable resources are being obtained from it. Researchers are now developing nanocomposites/blends from plastic wastes as a way of recycling waste plastic rather than employing incineration and landfilling methods of recycling that are not environmentally friendly. The utilization of nanofiller to recycle waste polymers will enhance the mechanical, thermal and optical properties of the recycled polymers that are repeatedly degraded when they are managed via incineration and landfilling. The aim of this study is to prepare and characterize SnO₂ nanofiller from recycled expanded polystyrene (rEPS) polymer wastes (PWs). A product was obtained, and it was characterized using BET, SEM and XRD. The BET showed microporous adsorption with surface area as 3.5880 m²/g, pore size 5.47314 m and the pore volume 0.004909 cm³/g, the SEM analysis showed spherical-shaped particles between 5 μm and 50 μm and the XRD indicated that the material is crystalline with tetragonal shape. This work showed a perfect way of upcycling waste polymers in a cost-effective manner and subsequently having the properties enhanced.

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1. Introduction

Tin is a member of the group 14 elements with oxidation numbers of +2 and +4 and has a wide range of applications in fuel cells, semiconducting nanowires and window coatings [1]. Researchers are currently carrying out investigations on various oxides of Tin because of its properties which include mechanical, optical and electrical properties [2]. Moreover, other synthetic routes to prepare oxides such as Tin dioxide (SnO_2) are also being investigated to discover other functional properties [3]. Some of the methods that have been widely used for the synthesis SnO_2 include sol-gel, polymeric precursors, hydrothermal, chemical precipitation, gas phase condensation and carbothermal reaction [3].

SnO_2 is a metal oxide with characteristics of semi-conductivity, high thermal stability and bulk band gap of 3.6 eV [4-7]. SnO_2 is applied in different areas like its utilization as catalyst in organic synthesis, ferroelectric, solid electrolyte, inorganic pigment, gas sensing material, and a component of optical and other functional materials [8-13]. SnO_2 as one of the synthesized nanofillers can be used to recycled waste polymers and the application of polymers through this route has both economic and environmental benefits [14]. Plastic wastes (PWs) can therefore be best recycled using nanofillers which lead to the improvement in the mechanical, thermal and optical properties and the performance of polymers [15-17].

The increasing usage of plastic materials has in recent time contributed to the large quantity of the municipal solid wastes (MSWs) generated all over the world. Thus, the world at large is currently faced with the challenges of plastic wastes (PWs) management owing to the acute accumulation of PWs that are generated from all sectors [15]. With the increasing environmental concern globally owing to the rapid generation of PWs especially in the developing countries (DCs), the development of nanofillers such as SnO_2 from plastic/polymer materials which will save the environment from pollution that arises from poor plastic waste management (WM) becomes very crucial [18]. The incorporation of nanofillers in the recycling of polymer wastes improve the performance of polymer which can be attributed to high surface area of nanomaterials which results to increase in the interfacial interactions between polymer and filler [19, 20].

The aim of this paper is to prepare and characterize SnO_2 nanofiller from expanded polystyrene wastes using hydrothermal synthesis technique.

2. Experimental section

1.1. Material and preparation process

Tin (II) chloride dihydrate ($\text{SnCl}_4 \cdot 2\text{H}_2\text{O}$), benzene (C_6H_6) and recycled expanded polystyrene (rEPS) were used in this experiment. Four (4g) of rEPS was dispersed in 50 mL of C_6H_6 . It was sonicated for 20 minutes. Four (4g) of $\text{SnCl}_4 \cdot 2\text{H}_2\text{O}$ was added to the solution and sonicated for another 20 minutes. The mixture was placed in an oven with the aid of hydrothermal autoclave reactor having 250 mL capacity. The temperature of the oven was set at 250 °C for 3 hrs. The product was cooled to room temperature and an ash coloured powdered nanofiller was obtained.

1.2. Characterisation of SnO_2 nanofiller

Brunauer–Emmett–Teller (BET) was used to determine the surface area, pore volume and pore size of the nanocomposites. This was achieved using adsorption isotherms from the Micromeritics BET ASAP 2020 at 77 ± 0.5 K under liquid nitrogen condition together with the BET equation. The temperatures were raised during the night and the sample vessels were degassed before further analysis such as surface area, pore volume and pore size were carried out.

Scanning Electron Microscope (SEM) was used to collect data from the polymer samples. The SEM images were taken via a SEM microscope (VEGA3 TESCAN, Tescan Brno-Kohoutovice, Czech Republic). A carbon coating, (QUORUM, Q150T) was used alongside the microscope for the analysis.

Rigaku D-MAX/IIA X-ray diffractometer (XRD) (operated at 40 kV, 30 mA) was used to study the crystallinity and phase composition of SnO_2 nanofiller over the 2θ range from 20° to 80° at the scan speed of 0.50 deg./min.

1. Result and Discussions

1.3. SEM analysis

The morphology of tin (IV) oxide nanofillers showed spherical-shaped particles and bead-like shape at different magnifications between 5 μm and 50 μm as shown in Fig. 1 a-d [21]. The synthesized nanofiller showed clustered structures at different magnifications [4].

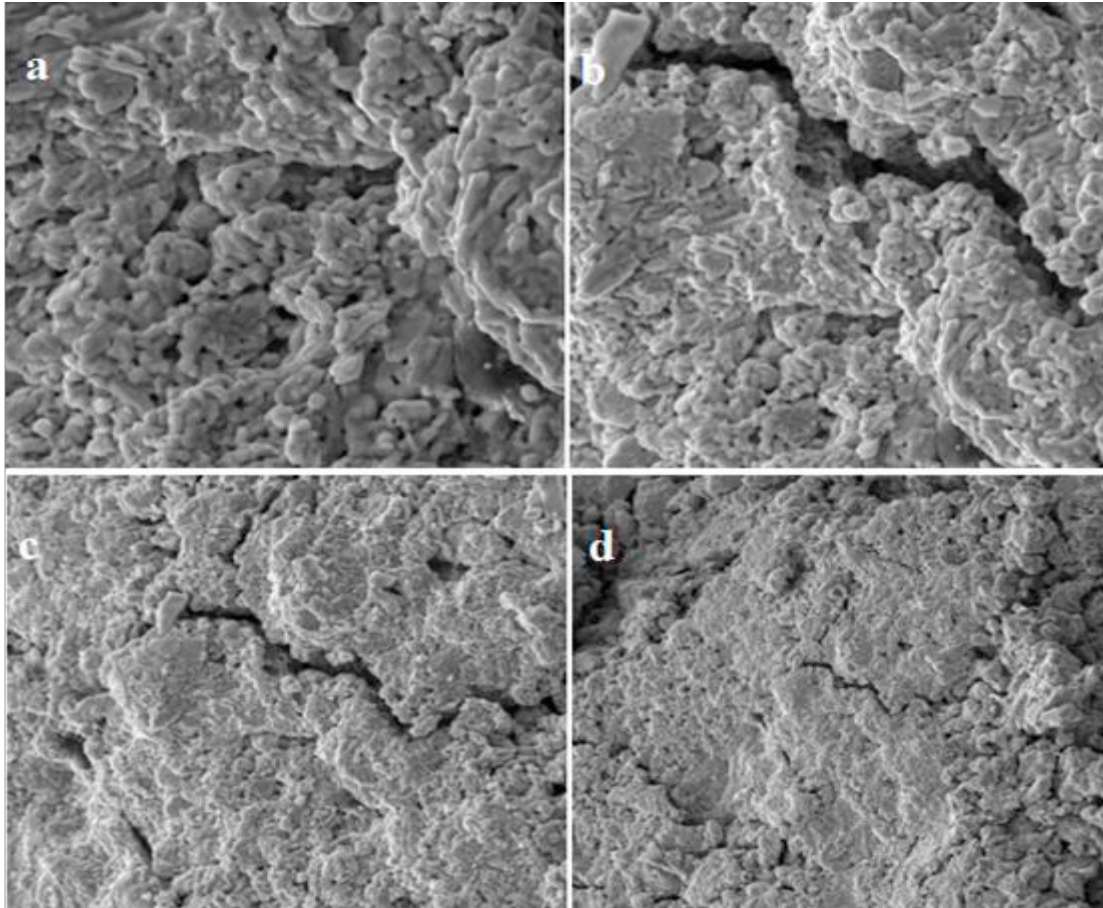


Fig 1. SEM images of different magnifications of SnO_2 nanofillers, a) 5 μm b) 10 μm c) 20 μm d) 50 μm

1.4. XRD analysis

The XRD image of SnO_2 is shown in Fig. 2. The peaks shown at 2θ of 26.9° , 33.7° , 38.2° , and 51.1° can relate to (110), (101), (200), and (211). Moreover, all the peaks of the SnO_2 nanofillers can be indexed to crystalline tetragonal shape. Also, at 2θ , the peak of 38.2° shown agreed with other previous published works by [22-24]. The particle

crystalline size is calculated by Debye Scherrer formula given by Equation 1.

$$B = k\lambda / s \cos\theta \quad (1)$$

Where s = crystalline size

λ = wavelength of the X-ray radiation (CuK α = 0.15406 nm)

k = constant to be taken as 0.94

θ = diffraction angle and

B = line width at half maximum height

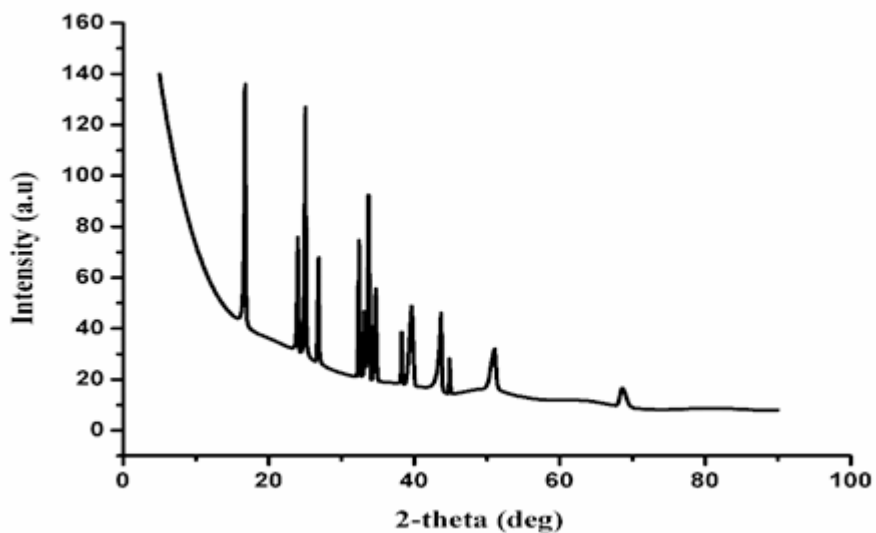
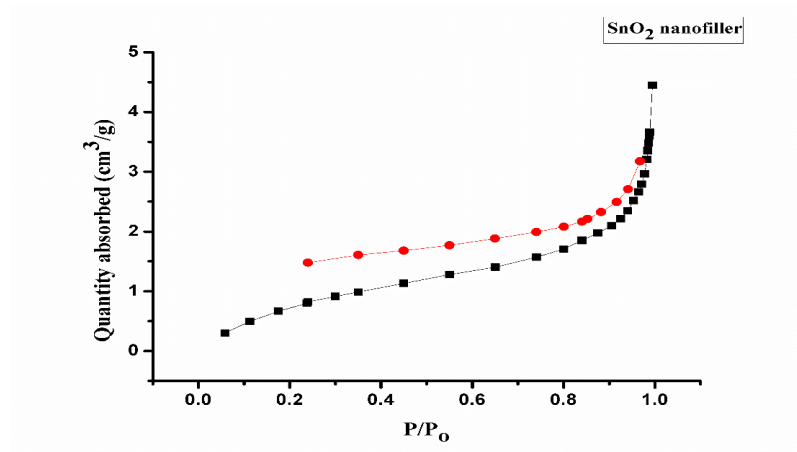


Fig 2. XRD spectra of SnO₂-nanofillers

1.5. BET analysis

The BET surface area, pore size and volume were evaluated when the adsorption isotherms of nitrogen were analysed on the mesoporous surface at a rising relative pressure. The surface area, pore size and pore volume were 3.5880 m²/g, 5.47314 m and 0.004909 cm³/g respectively [25]. The isotherm obtained is the reversible Type II isotherm having a macroporous adsorbent. The BET spectrum is shown in Fig. 3. This usually denotes an unrestrained monolayer-multilayer adsorption [26].

Fig 3. BET spectra of SnO₂ nanofillers

Conclusion

The potential to develop SnO₂ nanofiller from rEPS has been established from this study. The nanofiller developed will help to improve the mechanical properties of waste polystyrene that are often lost when landfilling and incineration are employed as waste management options. The nanofiller obtained was characterized by BET, SEM and XRD. The BET showed isotherm with a non-porous adsorbent with surface area of 3.5880 m²/g, pore size 5.47314 m and the pore volume 0.004909 cm³/g. The SEM images of the SnO₂ revealed spherical-shaped particles and bead-like shaped at different magnifications between 5 μm and 50 μm and the XRD analysis showed that the sample is crystalline with tetragonal shape.

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