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Optical properties of bimetallic (SrO-K₂O) nanofillers

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Abstract

In this study, bimetallic nanofiller capable of usage as reinforcement was synthesized from expanded polystyrene (EPS). Bimetallic materials consist of two different metals. The bimetallic nanofiller consisting of SrO and K₂O was successfully developed by the hydrothermal method which many researchers have well utilized to prepare nanoparticles in recent times. This study aims to synthesize and characterize bimetallic SrO-K₂O, nanofillers from recycled expanded polystyrene (EPS). Products obtained were characterized by Zeta potential and Raman spectra. The Zeta potential was used to determine the surface charge of the nanofillers in solution. The Raman spectroscopy was used to determine the crystalline structure of the nanofillers. Based on the results, it was concluded that stability of nanoparticle materials in acidic medium decreases as the pH increases, and for the basic medium, stability reduces with decrease pH. The mixture of SrO and K₂O to form SrO-K₂O bimetallic oxide affects the stability of the nanofillers produced both in the acidic and basic medium. The Raman spectra indicated the D_{band} and G_{band} of the synthesized SrO, K₂O and bimetallic SrO-K₂O at 1006, 1008 and 1004 cm⁻¹ and 1598, 1610 and 1606 cm⁻¹ respectively. It was concluded that the shift in band gaps were because of structural changes in the molecules of the recycled expanded polystyrene.

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1. Introduction

Dated back to 1980s, studies have shown that bimetallic materials possess improved efficiency compared to monometallic materials [1]. Bimetallic nanoparticles comprise of two dissimilar metals that have drawn attention from the scientific and technological domain in recent times and the structure of these materials are described by the ways the elements are distributed [2, 3]. Bimetallic nanoparticles metals are useful for applications like optical, magnetic and electric fields and can also be applied as nanofillers for reinforcement [4-6]. Lately, researchers have directed their interest towards the synthesis and usage of bimetallic nanoparticles because the properties of these materials are exceptional [7].

Moreover, recent studies have revealed that bimetallic nanoparticles indicate improvement in their properties which makes them effective catalysts for different applications [8]. When two metals are combined, the range of their properties are extended, which leads to enhancement in some specific properties. This is because of the range of their compositions, structures etc. [9]. Bimetallic nanomaterials possess distinctive combination of designs that helps to improve their practicality and they display enhanced stability and selectivity when they related to monometallic nanomaterials [10, 11]. The examples of these materials include $SrO-K_2O$. Strontium oxide (SrO) is a fine ceramic material which has a work function of about 1.27 eV [12]. This material retains an outstanding optical, thermal, high mechanical, chemical inertness and wide band gap. It is used in the production of glass in colour television, small direct current motors and dryers. Several methods which include sol-gel, chemical precipitation, hydrothermal have been used for the synthesis of SrO [13-16].

Because of all these properties, the oxide has become accepted lately. The grouped morphology of this oxide makes it suitable for designing devices used in different applications which include solar cells, transistors, electrodes etc. [12, 14, 17]. Potassium oxide (K_2O) is a material used in testing the existence of more compounds in chemical reactions and can as well be used to compound cement [18]. There are many minor compounds in Portland cement and K_2O is one of them and it happens to be one of the two minor compounds of interest and this makes it to be suitable for reinforcement [19].

The aim of this paper is to prepare and characterize a bimetallic nanofillers and compare with monometallic materials.

2. Experimental

2.1. Materials and sample preparation

The materials utilized in this study include; strontium carbonate ($SrCO_3$), potassium carbonate (K_2CO_3), benzene (C_6H_6), expanded polystyrene (EPS) wastes, and a 250 ml hydrothermal autoclave reactor. $SrCO_3$ was purchased from Honeywell Specialty Chemicals Seelze, Germany, K_2CO_3 was supplied by Protea Holdings Limited, South Africa, C_6H_6 was obtained from Glassworld & Chemical Suppliers CC, South Africa and the hydrothermal autoclave reactor was purchased from Protea Laboratory solutions Pty Ltd.

2.2. Sample preparation

Ten (10 g) of EPS was dispelled in a 100 mL of C_6H_6 and the sample was sonicated for 20 minutes. Five (5 g) each of $SrCO_3$ and K_2CO_3 were measured separately and were dispersed into the resulting solution and sonicated for another 20 minutes. The sample was kept in a hydrothermal autoclave reactor and kept in an oven for 3 hrs. at a temperature of 280 °C. Finally, a bimetallic product was obtained, and analysis was carried out on it.

2.3. Preparation of samples for Zeta potential analysis

Standard solution of HCl and NaOH purchased from Sigma Aldrich were used to adjust the pH. The range of the pH were 2, 4, 6, 8, 10 and 12. Three (3) mg of each of the three samples were dispersed into each solution according to the ranges of the pH. The samples were sonicated for 2 hours. Afterwards, the Zeta potential analysis was carried out on the samples.

2.4. Characterisation of SrO- K_2O nanofillers

The bimetallic nanomaterial obtained was characterized using Zeta potential and Raman spectra. The Zeta potential (Zeta Sizer Nano Series) was carried out on an instrument supplied by Malvern Instrument Ltd, South Africa. The Zeta potential was used to determine the surface charge of the nanofillers in solution. The Raman spectra was examined on Raman Microscope (PerkinElmer Raman Micro 200). The Raman spectroscopy was used to determine the crystalline structure of the nanofillers.

3. Result and Discussions

3.1. Zeta Potential

The application of zeta potential (ZP) as analytical tool has been gaining more attention in recent time. ZP is a vital tool that provides an understanding of the stability of nanoparticle (NP) materials and NP surface chemistry in relation to its charges in solution. The attraction of thin layer ions either (+ve/-ve ion) by the NP surface charge towards itself enables a double layer ion forms by ions attraction which migrate together with NP within a solution through diffusion. The magnitude of ZP gives a predictive or forecasting permutation of material stability in a solution (colloid). It ranges between +100 mV to -100 mV. When NP has a ZP greater than +25 mV or less than -25 mV, it gives an indication of the NP material having high degree of stability with poor dispersion rate. However, low ZP value lead to aggregate or agglomeration due to inter-particle attraction caused by Van Der Waal force. Also, NP with a poor dispersion rate in solution leads to low ZP value by Van Der force. Furthermore, the isoelectric point (IEP) of a colloidal suspension is the pH of a disperse medium after the colloidal particle possess no net charge (i.e. carry no charge). The IEP of a colloidal system is least stable due to inter-particle Van Der Waal repulsive force which is absence and together surface particle charges. Many metallic oxide NP become either neutral at certain pH or charge which is either positively or negatively by adsorption of (H^+) or (OH^-). Difference in IEP material is due to ZP of NP materials [20-23].

Figure 1 shows the graphical representation of SrO, K_2O and SrO- K_2O nanofillers. The stability of NP material in colloidal solution in acidic medium decreases as the pH increases i.e. as the acidic medium of the solution decreases, the stability of the SrO nanofillers increases for pH 2 and 4 while in basic medium, the stability of the nanofillers increase with increase pH for pH of 8 and pH of 10. Moreover, for pH of 12, the dispersion of the nanofiller is unstable due to repulsive force of interparticle Van Der Waal force and from the utilization of benzene as solvent during the synthesis of the nanofillers. The pH of 6 is least stable because of least H^+ charge available for dispersion/adsorption. The K_2O nanofillers is least stable in acidic medium (Figure 1). The more acidic the solution, the less stable the nanofillers for samples 1 and 2 at pH of 2 and pH of 4. Sample 3 at pH of 6 achieved the highest stability due to less H^+ available for absorption. Additionally, in the basic medium, the highest stability was achieved for sample 4 at pH of 8 while sample 6 at pH of 12 has least stability due to low ZP. Stability reduces with

decrease pH in basic medium. For the bimetallic samples (SrO-K₂O nanofillers), it is only the first sample at pH of 2 that is stable due to large ZP and high dispersion rate in solution. The mixture of SrO and K₂O to form bimetallic oxide affects the stability of the nanofillers produced in both the acidic and basic medium apart from the first sample which dispersed well in low pH of 2 and could be attributed to high H⁺ ion available for adsorption.

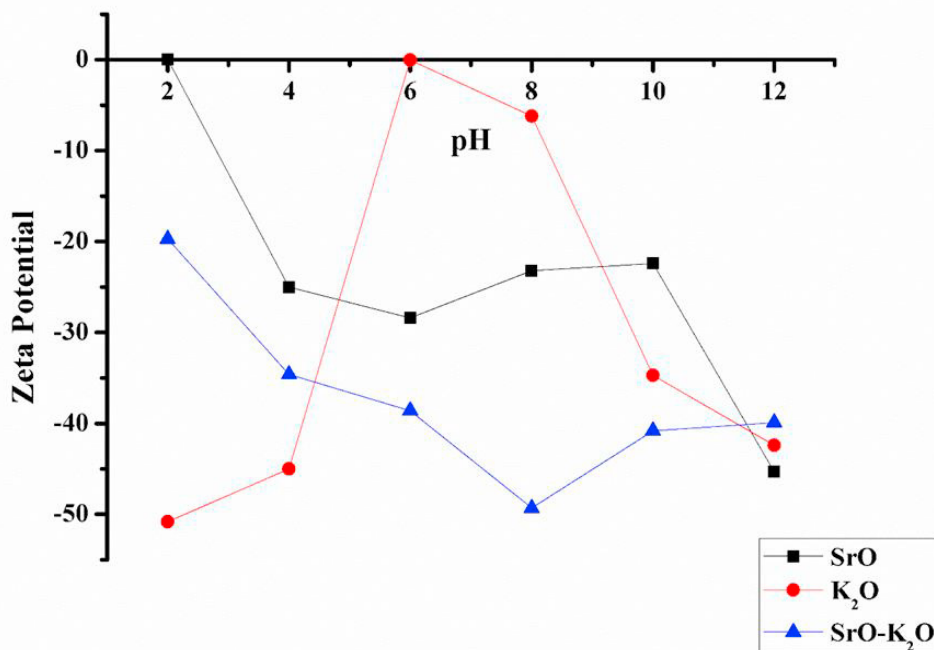


Figure 1 Zeta Potential Analysis

3.2. Raman Spectra

Raman spectroscopy as a method to investigate nanoparticles has gained interest in the research world in recent times [24]. Although, Raman spectroscopy cannot offer laser spots that are less than 1 μm in diameter but it should be noted that the spectra originate from the vibrations of chemical bonding [24]. The Raman spectra was used to detect bands forms from crystallinity present in the synthesized nanofiller. The Raman spectra (Figure 2) shows the D_{band} and G_{band} of the synthesized SrO nanofillers, K₂O nanofillers and SrO-K₂O bimetallic nanofillers. The D_{band} for SrO, K₂O and SrO-K₂O are 1006, 1008 and 1004 cm^{-1} and the G_{band} are 1598, 1610 and 1606 cm^{-1} respectively. Two peaks were observed for each of the nanofillers, one of them is closed to the D_{band} at 1006, 1008 and 1004 cm^{-1} and the other to the G_{band} at 1598, 1610 and 1606 cm^{-1} respectively. Tuinista-Koenig law states that the ratio of two peaks can be used to deduce sp^2 domain sizes. The shift in the band gaps were as a result of structural changes in the molecules of the recycled expanded polystyrene samples [25, 26].

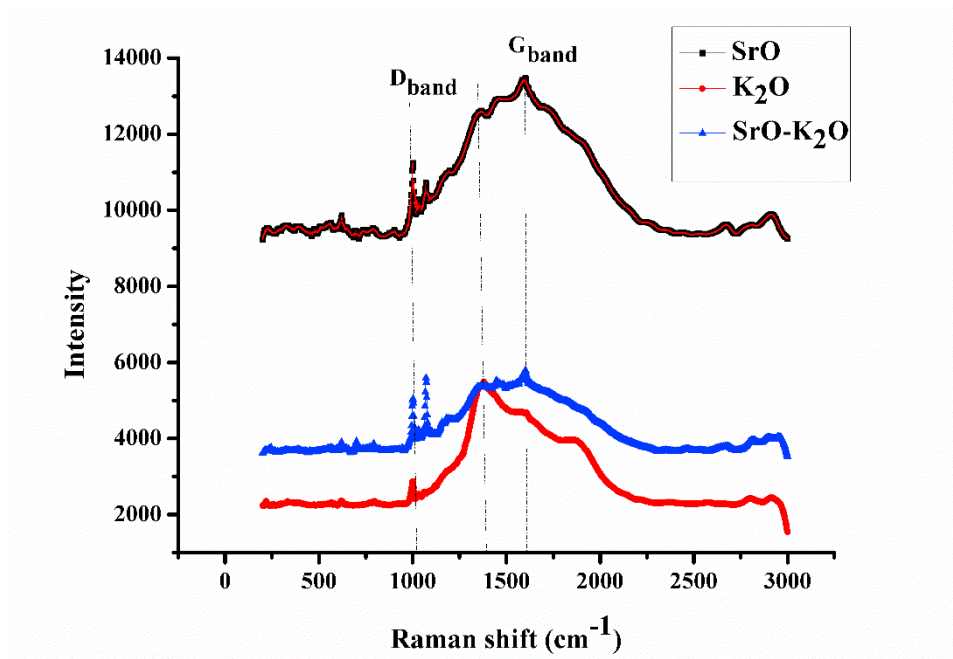


Figure 2 Raman Spectra

Conclusion

Bimetallic oxide nanofillers and other two monometallic nanofillers have been successfully synthesized through the hydrothermal synthesis routes of the preparation of nanocomposites. Zeta potential analysis and Raman spectroscopy analysis were carried out. For the Zeta potential analysis, the combination of SrO and K₂O to form bimetallic oxide affects the stability of the bimetallic nanofillers produced in both the acidic and basic medium apart from the first sample at pH of 2. The Raman spectra showed the D_{band} and G_{band} of the synthesized SrO, K₂O and SrO-K₂O nanofillers. The shift in the bands were attributed to structural changes in the molecules of the material used and changes in chemical bonds of the molecules due to internal or external effects.

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