



Nanocomposites Transformed from Polystyrene Waste/Antimony, Barium and Nickel Oxides Nanoparticles with Improved Mechanical Properties

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ABSTRACT: In this experiment, the oxide nanoparticles were synthesized via chemical precipitation and the nanocomposites were produced using in situ polymerization method with varying nanoparticles contents ranged from 0 to 5 g. The mechanical properties of the nanocomposites were investigated and compared with the values obtained for untreated polystyrene. It was observed that the mechanical properties were higher for the nanocomposites and increase with increasing nanoparticle concentrations in the samples. It can be observed that the untreated polystyrene gave a tensile strength of 945.25 N/mm². At high nanoparticle content of 5 g, the nanocomposite containing NiO nanoparticles showed a tensile strength of 973.83 N/mm² while nanocomposite containing BaO nanoparticles gave a tensile strength of 968.19 N/mm² and nanocomposite containing Sb₂O₃ nanoparticle gave a tensile strength of 955.53 N/mm². The results indicate that the tensile strength and percentage elongation of all the nanocomposites improved with the addition of metal oxides nanoparticles compared with the untreated polystyrene. Slight decrease in percentage reduction in area of the nanocomposites was recorded. Conclusively, with these results, the PS/NiO nanocomposite showed a better trend of behaviour due to better interfacial interaction between the nanofillers and the polymer matrix followed by PS/BaO and PS/Sb₂O₃ nanocomposites. It is recommended that during the production of polymer nanocomposite, PS/NiO, PS/BaO and PS/Sb₂O₃ nanocomposites could be used as reinforcements in the construction of buildings to add structural stability to the building.

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Polystyrene is one of the most widely used plastics, the scale of its production being several million tonnes per year (Maul *et al.*, 2007). Polystyrene can be naturally transparent, but can be coloured with colourants. Polystyrene has varieties of applications among which include: It is used in furniture industry, refrigerators and production of toys, etc. Furthermore, clear plastic drinking cups as well as a lot of the molded parts inside cars are made of polystyrene, for instance radio knobs. Polystyrene is also used in toys, hair dryers, television, and kitchen appliances (Maul *et al.*, 2007). It is used in packaging and as a cushioning agent. Polystyrene is mainly used in building and construction (around 70 %), around 25 % of polystyrene is used in packaging and 5 % in other applications (Cole, 2014). Polymer nanocomposites are hybrid organic-inorganic materials with at least one dimension of the filler phase less than 100 nm. Nanocomposites are composites in which at least one of the phases show dimensions in the nanometre range (1 nm = 10⁻⁹ m) (Schmidt *et al.*, 2002). Nanocomposite materials have emerged as suitable alternatives to overcome limitations of microcomposites and monolithics, while posing preparation challenges related to the control of elemental composition and stoichiometry in the nanocluster phase (Schmidt *et al.*, 2002). It is reported to be the materials of 21st century in the view of possessing design uniqueness and property combinations that are not found in conventional

composites (Schmidt *et al.*, 2002). Nanoparticles were considered to have a size range between 1 and 100 nm (Mittal, 2010). The term "nanoparticle" is not usually applied to individual molecules; it usually refers to inorganic materials. Nanoparticles are particles between 1 and 100 nanometres (nm) in size with a surrounding interfacial layer. The interfacial layer is an integral part of nanoscale matter, fundamentally affecting all of its properties. However, it has been shown that particles larger than 50 nm show no significant properties of materials as expected (Mittal, 2010). Mechanical properties of polystyrene/clay nanocomposites considerably depend on the morphology of the synthesized nanocomposites, as well as on the applied polymerization technique (Cole, 2014). It has been shown that desired and better improvements of mechanical properties can be obtained when polystyrene/clay nanocomposites have exfoliated structure. On the other hand, polystyrene/clay nanocomposites which have intercalated structures display a decrease in the tensile strength, which could be due to the formation of voids in the structure (Cole, 2014). The presence of voids weakens the interaction between clay and polymer, leading to the decrease of tensile strength and elongation. According to Cole (2014) introduction of 5 wt% ZnO nanoparticles into polystyrene decreased both the tensile strength and elongation at break. This implies that the interfacial adhesion is not strong

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enough to stand up to large mechanical forces, because the homogeneous dispersion of nanoparticles was difficult. The presence of ZnO nanoparticles in the polystyrene film, makes it highly transparent in the visible range, offers prospects of application of these nanocomposites as transparent UV radiation protectors in the wavelength range from 200 to 360 nm. The increscent growth in the amount of polystyrene wastes into the environment is due to the booming development of electronic products. The disposal of polystyrene wastes creates environmental pollution and contamination due to their non-degradable nature. According to Cole (2014) scientific research had shown that the solution to these problems is achieved through recycling method and transforming them to smart and useful materials. This research work desires to provide information on transforming polystyrene wastes to nanocomposites with improved mechanical properties. Apart from the numerous advantages of polystyrene in buildings, electronics and other applications, circumstances where polystyrene wastes are recycled and transformed into useful materials are rarely found. Transforming polystyrene wastes to useful materials will reduce the effects of environmental pollutants on animals, plants and humans. It will also prevent wastes from entering into landfills. The negligence of transforming polystyrene wastes to useful materials has attracted a lot of attention in the field of research whereas, the recycling of polymers to nanocomposites with improved mechanical properties have not been adequately and sufficiently studied. Therefore, this research work will bring about knowledge that is of utmost importance in the field of research. The aim of this research is to convert polystyrene wastes to nanocomposites with improved mechanical properties. The objective of this research is to evaluate the mechanical properties of formulated nanocomposites for possible applications in buildings.

MATERIALS AND METHODS

Materials: The materials used include; razor blade, instron machine OKH-1000 WE, stop watch, magnetic stirrer JB-4A, analytical weighing balance JT 2003A.

Collection of Polystyrene Wastes: Polystyrene waste samples were collected from a refuse dump site located at latitude 10^o17'57"N and longitude 9^o50'06"E Jahun in Bauchi State Nigeria.

Chemicals and Reagents: In this work or research, the nanoparticles of NiO, BaO and Sb₂O₃ used were synthesized in the Laboratory of Department of Chemistry, Abubakar Tafawa Balewa University, Bauchi. The solvents and reagents used were obtained in the laboratory and were of great analytical reagent grade such as ethanol (Emerk Darmstadt Company), toluene (BDH Laboratory reagent), methanol (Emerk Darmstadt Company), sodium hydroxide (Kermel), sodium bicarbonate (Kermel Company), nickel

sulphate (AR Guandong Chemicals), and barium nitrate (JHD Company), antimony trichloride (Tited Biotech Ltd).

Dissolution of Polystyrene (PS): The polystyrene wastes were rinsed off and washed several times with detergent and water to remove any food or dirt particles and dried in the laboratory. The samples (PS wastes) were crushed so that they can be fit into the container. Polystyrene waste (4g) was dissolved in 20 cm³ of toluene (solvent) in a conical flask and stirred for 30 minutes using magnetic stirrer of model JB-4A. The solution was then allowed to be heated for 30 minutes at 60 °C to form a solution (Achilias *et al.*, 2009).

Preparation of Nanoparticles

Preparation of BaO Nanoparticles: In this research, a wet chemical precipitation method was used to obtain the metal oxide nanopaticles. Sodium bicarbonate (0.4 M) was added to the 0.2 M solution of barium nitrate drop wise, under constant stirring for 2 hours until addition of sodium bicarbonate solution was complete. After the completion of the reaction, the precipitates formed were allowed to settle overnight. The solution was filtered off and washed several times with distilled water until free from excess bicarbonate. A white precipitate formed was then allowed to dry in oven at 80 °C for 1 hour and then calcined at 150 °C for 3 hours to form the desired barium oxide nanoparticles (Prabhavathi *et al.*, 2014).

Preparation of NiO Nanoparticles: The method reported by Vivek *et al.* (2014) was adopted. A solution of nickel sulphate (1.0 L, 0.11 M) was taken and aqueous ammonia was added drop wise with constant stirring using magnetic stirrer of model JB-4A until the pH of 10 was reached. The precipitate formed was filtered and washed several times with distilled water. The precipitate formed was allowed to dry in oven at 70 °C for 24 hours and calcined at 600 °C in a muffle furnace for 5 hours to form the desired nickel oxide nanoparticles.

Preparation of Sb₂O₃ Nanoparticles: The method reported by Cheng *et al.* (2008) was used to obtain Sb₂O₃ nanoparticles. 0.1 M solution of antimony trichloride was dissolved in 500 cm³ of ethylene glycol under vigorous stirring to form a transparent solution. Subsequently, 500 cm³ of distilled water was added to the solution and stirred for 15 minutes, 6 M solution of sodium hydroxide (NaOH) was added to adjust the pH.

The whole solution was stirred for 20 minutes before transferring it into an autoclave at 120 °C. After 12 hours, the product formed was centrifuged and washed several times with distilled water and ethanol and then dried at 60 °C for 6 hours to obtained the required antimony oxide nanoparticles (Sb₂O₃) (Chen *et al.*, 2008).

Formation of Nanocomposites: In this experiment, an *in situ* polymerization method was used to obtain the desired nanocomposites. The nanocomposites were formed by varying the concentrations of BaO, NiO and Sb₂O₃ nanoparticles as 0 g, 4 g and 5 g and taking the concentration of polystyrene solution as constant (30 ml). The nanoparticles were incorporated directly into the polymer solution and stirred for 1 hour using magnetic stirrer of model JB-4A.

The mixture was maintained at 60 °C for 20 hours to promote *in situ* polymerization. The products formed were poured into excess methanol and stirred for 15 to 20 minutes and washed several times with ethanol and water. The products formed were dried in oven at 80 °C overnight to obtain the desired nanocomposites.

Mechanical properties

Determination of Tensile Testing: In this experiment, an *in situ* polymerization method according to Edreese (2016) was used to obtain the desired nanocomposites. The nanoparticles of varying concentration of 4 g and 5 g for nickel oxide, barium oxide and antimony trioxide were incorporated separately into the polymer solution of constant volume of 10 cm³ and stirred for 1 hour using magnetic stirrer of model JB-4A.

The mixture was maintained at 60 °C for 20 hours to promote *in situ* polymerization. The products formed were poured into excess methanol and stirred for 15 to 20 minutes and washed several times with ethanol and water. The products formed were dried in oven at 80 °C overnight to obtain the desired nanocomposites. Tensile testing was performed to determine the breaking force, percentage elongation and the percentage reduction in area.

Determination of Tensile strength: The composites were cut into rectangular shapes with dimensions of 150 mm length and 15 mm width. In tensile testing, a “dog-bone” shaped sample was placed in the grips of movable and stationary fixtures in an instron machine of model OKH-1000 WE which pulls the sample until it breaks as indicated by red arrow as shown in Figures 2 and 3 below. The applied load versus elongation of the sample was measured (Boryo *et al.*, 2010 and Boryo *et al.*, 2013). The tensile strength of the materials was calculated using the formula below (Boryo *et al.*, 2010 and 2014):

$$T = \frac{F}{A} \quad (1)$$

Where F is the Failure load in (Newton) and A is the area in (mm²)

$$A = \pi D^2 / 4 \quad (2)$$

Where A is the area in mm² and D is the diameter in mm. $\pi = \frac{22}{7}$

The procedure was repeated for the untreated polystyrene and nanocomposites containing nickel oxide, barium oxide and antimony trioxide nanoparticles.



Fig 1: Image of Sample before Elongation without Breakage



Fig 2: Image of Sample after Elongation Showing Breakage

Determination of percentage elongation (% elongation): The percentage elongation (% Elongation) of the material was calculated using the formula (Boryo *et al.*, 2010 and 2014).

$$\% E = \frac{DL}{L1} \times 100 \quad \text{---- (3)}$$

Where DL is the change in length and L1 is the original length of material.

Determination of percentage reduction in area: And percentage reduction in area (% RA) was also determined using the formula;

$$\% RA = L1 - \frac{L2}{L1} \times 100 \quad \text{- (4)}$$

Where L1 is the original area in and L2 is the final area of material in mm²

RESULTS AND DISCUSSION

The effects of formulated nanocomposites on tensile strength are shown in Figures 3, 4 and 5. From Figures 3, 4 and 5 above, it can be observed that addition of nanoparticles into polymer matrix significantly improved PS polymer mechanical properties. It can be observed that the untreated polystyrene gave a tensile strength of 945.25 N/mm². Addition of nanoparticles into the polystyrene matrix improved the tensile strength of nanocomposites. At 4 g and 5 g concentrations of nanoparticles, the nanocomposite containing NiO nanoparticles showed increase in tensile strength from 969.79 N/mm² to 973.83 N/mm² as shown in Figure 3 above, while nanocomposite containing BaO nanoparticles gave a tensile strength of 959.32 N/mm² and 968.19 N/mm² as shown in Figure 4 and nanocomposite containing Sb₂O₃ nanoparticle gave a tensile strength of 948.99 N/mm² and 955.53 N/mm² as shown in Figure 5 respectively.

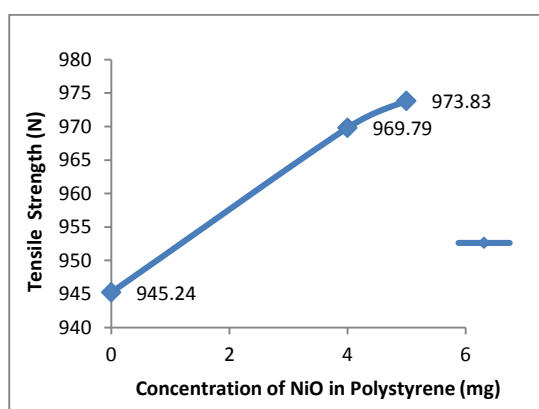


Fig 3: Effect of NiO Nanoparticles on Tensile strength of PS/NiO Nanocomposite.

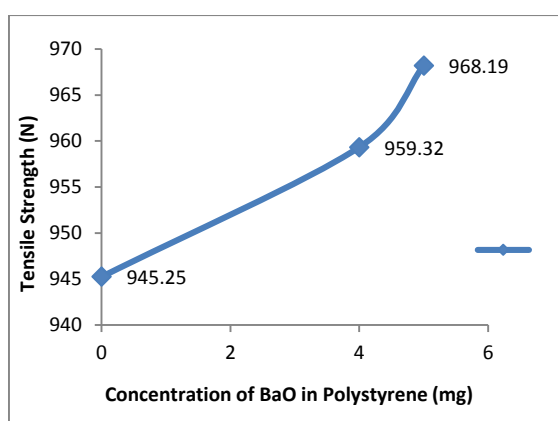


Fig 4: Effect of BaO Nanoparticles on Tensile Strength of PS/BaO Nanocomposite

The overall result showed that nanocomposites containing NiO nanoparticles gave the best tensile strength while nanocomposite containing BaO nanoparticles gave a better tensile strength and nanocomposite containing Sb₂O₃ gave a good tensile strength. This is because Ni is a transition metal (a heavy metal) and most transition metals are ductile, hard and tough. This result conforms to the result

obtained by Boryo *et al.* (2010) that tensile strength of PVC strip increased with increasing fire retardants concentrations. From the result obtained by Boryo *et al.* (2010) it showed that urea gave the highest tensile strength of the PVC strip followed by borax and lastly ammonium phosphate.

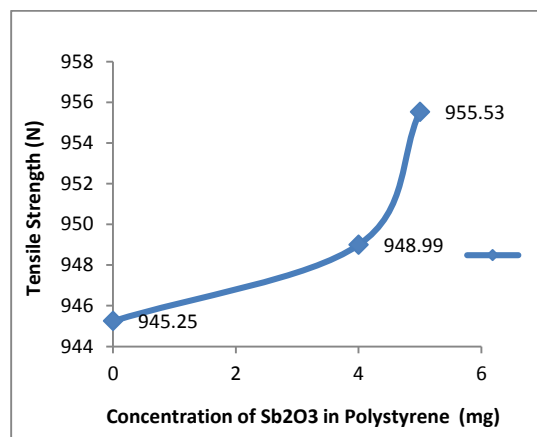


Fig 5: Effect of Sb₂O₃ Nanoparticles on Tensile Strength of PS/Sb₂O₃ Nanocomposite.

Table 1: Effect of Nanoparticles on Percentage Elongation (%)

Amount of Nanoparticles	Percentage Reduction in Area of Nanocomposites (%)			
	Untreated PS	PS/NiO	PS/BaO	PS/Sb ₂ O ₃
0	46.67	-	-	-
4	-	50.00	53.33	53.43
5	-	50.07	54.00	54.20

The result in Table 1 above showed that untreated polystyrene gave a percentage elongation of 46.67%. It can be observed that the percentage elongation of PS/NiO nanocomposite increase from 50.00% to 50.67% with increasing NiO nanoparticles concentration. It can also be observed from Table 1 that, PS/BaO nanocomposite showed increase in the percentage elongation from 53.33% to 54.00% as concentration of BaO nanoparticles increases while the nanocomposite containing Sb₂O₃ nanoparticles showed increase in the percentage elongation from 53.43% to 54.20% respectively.

Table 2: Effect of Nanoparticles on Percentage Reduction in Area of Nanocomposites

Amount of Nanoparticles	Percentage Reduction in Area of Nanocomposites (%)			
	Untreated PS	PS/NiO	PS/BaO	PS/Sb ₂ O ₃
0	47.66	-	-	-
4	-	47.58	47.20	47.18
5	-	44.67	43.91	43.76

The overall result showed that nanocomposites containing NiO nanoparticles gave the best percentage elongation while nanocomposite containing BaO nanoparticles gave a better percentage elongation and nanocomposite containing Sb₂O₃ gave a good percentage elongation. This is because Ni is a

transition metal (a heavy metal) and most transition metals are ductile, hard and tough while metalloids (antimony) are not.

The result in Table 2 above showed that untreated polystyrene gave a percentage reduction in area of 47.66 %. From Table 2, it can be observed that the percentage reduction in area of PS/NiO nanocomposite decrease from 47.58 % to 44.67 % with increasing NiO nanoparticles concentration. It can also be observed that from Table 2, PS/BaO nanocomposite showed decrease in percentage reduction in area from 47.20 % to 43.91 % as concentration of BaO nanoparticles increases. The result in Table 2 also showed that the nanocomposite containing Sb₂O₃ nanoparticles also showed decrease in the percentage reduction in area with increasing concentration from 47.18 % to 43.76 %.

The overall result clearly showed that tensile strength increases with increasing concentration of nanoparticles. The results in Figures 3, 4, 5 and Tables 1 and 2 showed that nanocomposites containing NiO nanoparticles gave better mechanical properties due to interfacial interaction followed by nanocomposites containing BaO nanoparticles and nanocomposite containing Sb₂O₃ nanoparticles respectively.

This result conforms to the result obtained by Boryo *et al.* (2014) that all the mercerizing agents improved the breaking force of the samples. This is confirmed by the significant improvement in breaking load as compared to that of untreated samples (9.75 kgf). With respect to the control treatment, there is a very close competition with the alternative agents.

Conclusion: Based on the present findings, it can be concluded that there have been improvements in the mechanical properties of the nanocomposites produced as the nanofiller content increases even though the different fillers imparted different degrees of mechanical improvement to the polymer. It is recommended that during the production of polymer nanocomposite, PS/NiO, PS/BaO and PS/Sb₂O₃ nanocomposites could be used as reinforcements in the construction of buildings to add structural stability to the building.

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REFERENCES

Achilias, DS; Antonakou, W; Koustokosta, E; Lappas, A (2009). Chemical Recycling of Polymers from WEEE. *J. of Appl. Poly. Sci.* 114 : (6), 212-221

Boryo, DEA; Ezeribe, AI; Mustapha, AO; Aliyu, J (2010). Effects of Urea, Borax and Ammonium Phosphate on Fire Retardant and Mechanical Properties of Plastic Obtained from Polyvinyl Chloride. *J. of Chem. Soc. of Nig.* 32(2): 11-16.

Boryo DEA; Bello, KA; Ibrahim, AQ; Gin, NS; Ezeribe, AI; Wasiu, KA (2014). Effects of Alternative Mercerizing Agents on Mechanical Properties of Cotton/Polyester Blend Fabric. *Acad. J. of Interdisc. St.* 3(5):91-103

Chen, XY; Huh, HS; Lee, SW (2008). Synthesis of antimony oxide by hydrothermal method. *J. of sol. St. Chem.* 181: 2127

Cole, L [Ed.] (2014). Polystyrene Synthesis, Characterization and Application. New York; Nova Publishers, Inc. Pp 1-2, 205-206, 201-212, 213-230.

Maul, J; Frushour, BG; Kontoff, JR; Eichenauer, H; Ott, KH; Schade, C (2007). "Polystyrene and Styrene Copolymers" in Ullmann's *Encycl. of Ind. Chem.* Wiley-VCH, Weinheim, p 3.

Mittal, V (2010). in Optimization of Polymer Nanocomposite Properties (ed. V. Mittal), Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim, pp. 1-19.

Prabhavathi, PSJ; Punitta, P; Shameela, RR; Ranjith, G; Suresh, NM; Manithamithu, D (2014). Method of Synthesis of Copper Oxide, Zinc Oxide, Lead Oxide and Barium Oxide Nanoparticles. *J. of Chem. and Pharm. Res.* 6(3):1472-1478.

Schmidt, D; Shah, D; Giannelis, EP (2002). New advances in polymer/layered silicate nanocomposites. *Cur. Opin. in Sol. St and Mat. Sci.* 6(3):205-212.

Vivek, SJ; Avnish, KA; Mayank, K; Vishnu D; Joginder, S (2014). Synthesis and Characterization of Chromium Oxide Nanoparticles. *Oriental J. of Chem.* 30:2 559-566.