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RESEARCH PAPER

Tailoring Electrical Performance of PVA-PVP-SiC Composites Using NiO Nanofillers

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ABSTRACT

The morphological, structural, and insulating impacts of adding NiO nanoparticles to PVA-PVP-SiC-based polymer composites are investigated in this work. PVA/PVP/SiC/NiO composites at various concentrations (0.0, 0.3, 0.7, and 1 percent by weight) were made via casting. Additionally, the addition of nanobubbles using an ultrasonic device demonstrated that these compounds have special qualities in comparison to other nanocomposites and greatly improved insulation because the nanoparticles increased the number of charge carriers in the polymer system and enhanced polarization. When the compound level reached 1% by weight, the dielectric constants and electrical conductivity dramatically increased by 40% and 21%, respectively, due to the buildup of charges at the particle-polymer interfaces. Because NiO compounds are semiconducting, they have continuously improved. FE-SEM and optical microscopy (OM) techniques were used to analyze the compounds' structural characteristics. Additionally, the insulating qualities were investigated between 100 Hz and 5 MHz. These findings suggest that NiO compounds can be employed in a variety of nanodielectric materials and are more effective in enhancing electrical insulation.

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INTRODUCTION

Polymer nanocomposites have garnered considerable scientific and industry interest because to their remarkable potential for a variety of applications. The intriguing science of nanotechnology has the potential to raise our standard of living. A copolymer or polymer with nanoparticles or nanofillers dispersed throughout the polymer matrices makes up polymer nanocomposites [1,2]. Installing the polymer-based nanocomposite is a critical component of nanotechnology for the utilization of polymers. The use of nanometric inorganics as nanofiller in polymer-based nanocomposites is a unique strategy that deviates from the traditional addition of polymer [3]. Polymers' properties are not significantly better than those of other materials, such clay and most metals, which restricts their use in the manufacturing of products and structures [1,4]. Improvements in polymer properties lead to a wide range of applications. The inorganic filler contained within the polymers is what determines them. Solvent casting techniques are thought to be the most straightforward and time-efficient method for

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installing polymer nanocomposites to be the most significant ones that enhance the properties of the nanocomposites if they are successful [5-7]. For a variety of reasons, polyvinyl alcohol (PVA), one of the first and most widely used polymers, is widely utilized in semiconductor applications. Polyvinyl alcohol, or PVA, dissolves readily in water and chemical solutions that include hydroxyl [8,9]. Polyvinylpyrrolidone (PVP), a common hydrophilic synthetic polymer, is well-known for electrospun nanofibers due to its exceptional film organization properties. The structural properties of polymers are being greatly enhanced by metal oxides (MO). For example, nickel oxide (NiO), a stable semiconductor, can be used for gas detection, electrochemical capacitance, solar photovoltaic, cancer prevention in bio-frameworks, and other applications [10]. both mechanical stability and thermal conductivity. Depending on the poly-typecs, their broad band gap ranges from 2.3 to 3.4 eV [11]. Applications for silicon's exceptional resistance to oxidation include sensors for severe environments, thermal management materials, and abrasives [12]. It is also utilized in optoelectronics, composite reinforcement, and catalytic supports due to its strong mechanical and thermal characteristics [13]. The toxicity of organic materials is one of the disadvantages of employing them in sterilizing procedures, which has raised interest in inorganic disinfectants like metal oxide nanoparticles (NPs) [14]. Because they can be generated in unusual crystalline shapes and have very high surface areas, high-ionic metal oxide nanoparticles are regarded as particularly significant antibacterial agents [15]. Metal oxide nanoparticles including ZnO, CuO, and NiO have antibacterial properties, although they are not very efficient against foodborne illnesses [16]. Investigating the possible uses of silicon carbide (SiC) nanoparticles and their impact on the alternating current (A.C.) electrical characteristics of PVA-PVP-SIC-NiO nanocomposites for use in diverse optoelectronic applications is the aim of this work.

The PVA–PVP–SiC–NiO nanocomposites were prepared using the sol-gel technique with the aim of obtaining highly homogeneous nanocomposite samples and improving porosity. Initially, (1 gram) of polyvinyl alcohol (PVA) was dissolved in (60 ml) of distilled water using a magnetic stirrer at a temperature of (75 ± 3) °C, and the dissolution process continued for 30 minutes until complete dissolution. After that, polyvinylpyrrolidone (PVP) was added to the solution, and stirring continued for 20 minutes at the same temperature to obtain a homogeneous polymer solution. After completing the preparation of the base solution, it was divided into four main samples. The first sample was a pure sample containing only a mixture of PVA and PVP without any nanomaterials. As for the other three samples, different weight percentages of silicon carbide (SiC) and copper oxide (NiO) particles were added, namely: 0.3%, 0.7%, and 1% respectively, with the aim of studying the effect of nanomaterial concentration on the structural, optical, and electrical properties of the

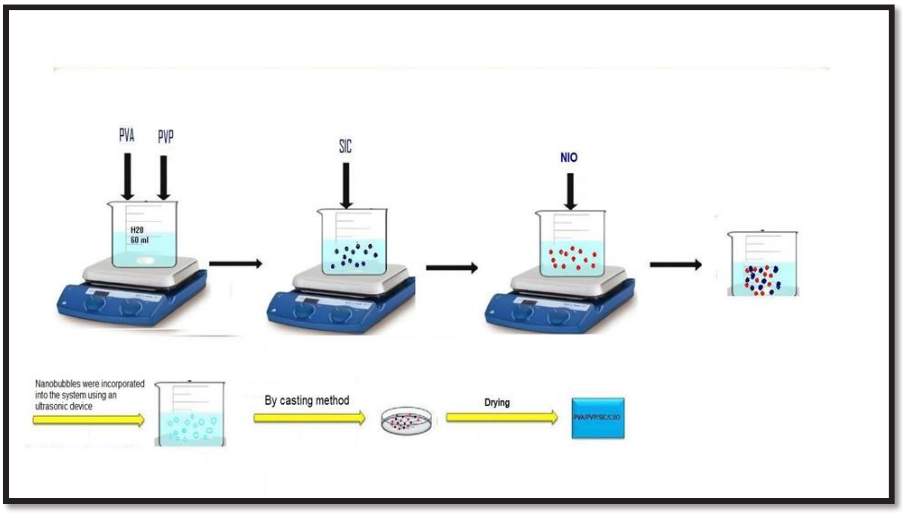

Fig. 1. Scheme of experimental work.

samples. After mixing the nanomaterials with the polymers, the mixture underwent an important stage that involved introducing air bubbles into the solution using a tube connected to an air compressor, where the tube was immersed in the cup of solution to generate fine air bubbles. At the same time, the mixture was placed in an FS-1200N ultrasonic processor at a frequency of 20 kHz for one minute. This step effectively contributed to converting large bubbles into stable nano-bubbles within the polymer matrix, enhancing their uniform distribution and increasing porosity. In the final stage, all samples were poured into clean and uniform Petri dishes and left to dry at room temperature for seven consecutive days to obtain solid and homogeneous nanofilms. As shown in the following Fig. 1.

MATERIALS AND METHODS

Polyvinylnickel alcohol-silicon carbide-oxide nanocomposites with 1.5 weight percent nickel oxide nanoparticles and 98.5 weight percent PVA were made using the casting method. Silicon carbide nanoparticles were added to PVA-NiO in weight percentages of 1.5%, 3.5%, 4.5%, and 6% to create PVA-NiO-SiC nanocomposites. Dielectric materials can store electrical energy in the form of charge separation when an external electric field polarizes the electron distributions surrounding constituent atoms or molecules. The complex permittivity of a material can be expressed as Eq. 1 [17]:

$$\varepsilon^{*} = \varepsilon_{a} - j\varepsilon_{b} \tag{1}$$

In this case, j = √-1 and ε_a and ε_b represent the real and imaginary components of the complex permittivity. Eq. 2 provides the real part of the permittivity [17].

$$\varepsilon_{a} = \varepsilon_{0}\bar{\varepsilon} \tag{2}$$

A substance’s ability to store energy from an applied electric field is indicated by its dielectric constant, or ε_a. The Eq. 3 [18] can be used to determine the capacitance of a capacitor consisting of two parallel plates.

$$C = \bar{\varepsilon}\varepsilon_{0}\frac{A}{t} \tag{3}$$

where t is the sample thickness, ε^2 is the vacuum permittivity, and ε^2 is the dielectric constant. Eq. 4 provides the dielectric constant [19].

$$\bar{\varepsilon} = \frac{C_{p}}{C_{0}} \tag{4}$$

In this case, Co stands for vacuum capacitor and Cp for parallel capacitance. A portion of the applied electric field energy dissipates when a

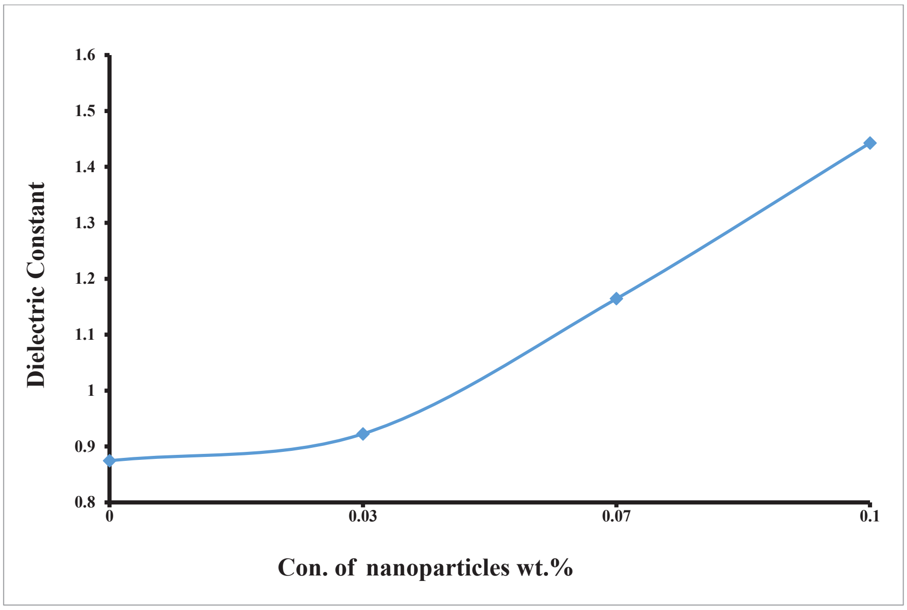

Fig. 2. The dielectric constant of PVA-PVP-SiC nanocomposites with NiO concentration.

material's polarization changes as a result of charge migration (conduction) or conversion into thermal energy (molecular vibration). The necessity for pulse power applications has long been met by ceramic capacitors made of highly polarizable inorganic materials [20,21]. The dielectric loss (ε″) is provided by Eq. 5:

$$\varepsilon'' = \varepsilon' D \qquad (5)$$

The dispersion factor is represented by the letter D. This illustrates the amount of electrical energy lost from the applied field and converted into thermal energy inside the sample. The presence of alternating potential as a function of alternating conductivity, which is described as [22], characterizes the dissipated power in the insulator (Eq. 6).

$$\sigma_{ac} = \omega\, \varepsilon''\, \varepsilon_0 \qquad (6)$$

where the angular frequency is denoted by ω.

RESULTS AND DISCUSSION

At a frequency of 100 Hz, the dielectric constant in (PVA-PVP-SiC-NiO) composites changes with the concentration of nanoparticles. The concentration of NiO particles in the nanocomposites increases their dielectric constant, as shown in Fig. 2. This behavior can be explained by the interfacial polarization in the nanomaterials under the applied alternating electric field and the increase in charge carriers [23].

Fig. 3 illustrates how the dielectric constant (PVA-PVP-SiC-NiO) varies with frequency.The figure shows that when the applied field frequency increases, the nanocomposite samples' dielectric constant drops. This is explained by the dipoles' propensity to align in the direction of the applied electric field in the nanocomposite samples This causes the surface charge polarization to decrease to the total polarization [24].

Fig. 4 illustrates how SiC nanoparticle concentrations affect the electrical loss (PVA-NiO) at 100 Hz. The electrical loss (PVA-PVP-SiC-NiO) increases as the concentration of NiO nanoparticles increases, as seen in the figure. As the concentration of NiO nanoparticles rises, the electrical loss of (PVA-PVP-SiC-NiO) increases along with the number of charge carriers. Fig. 4 shows

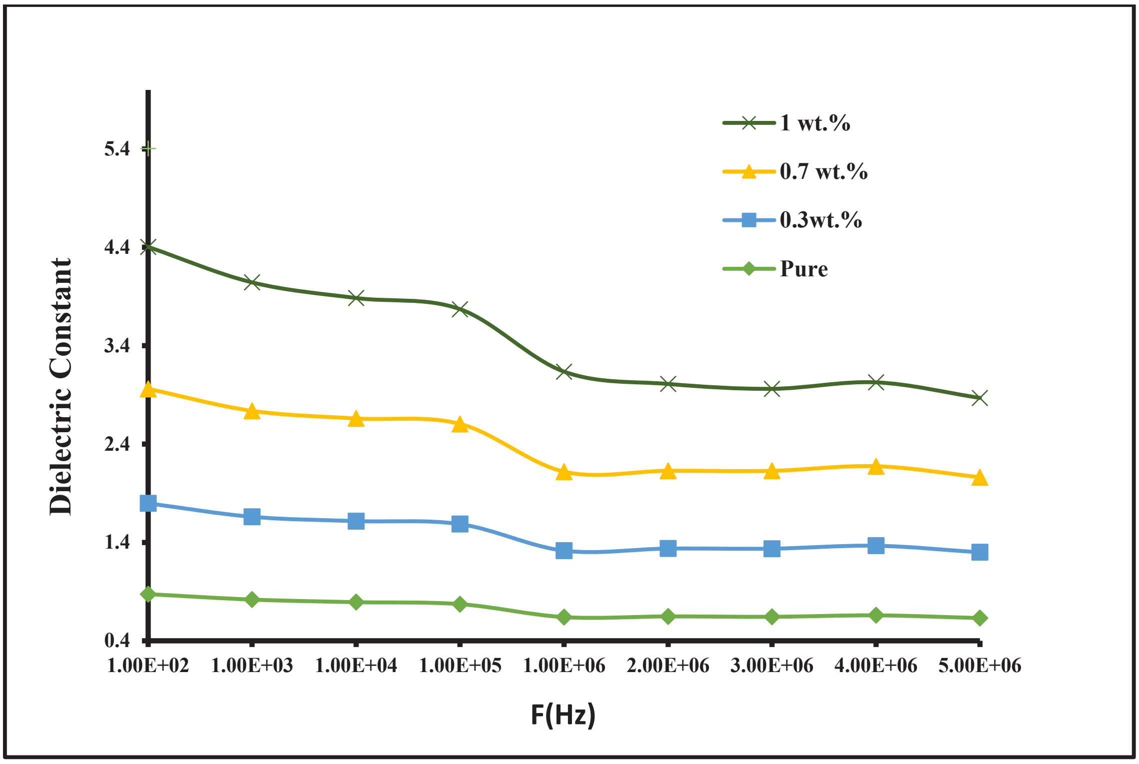

Fig. 3. PVA-PVP-SiC-NiO nanocomposites' dialectical constant with frequency.

how electrical loss (PVA-PVP-SiC-NiO) varies with frequency. As the applied electric field frequency increases, the dielectric loss of the nanocomposite elements decreases due to the diminished contribution of surface charge polarization. Fig. 5 illustrates that the dielectric loss for the nanocomposite materials (PVA-PVP-SiC-NiO) is considerable at low frequencies and reduces with increasing frequency because the electrodes have adequate time to align with the applied electric field before the electric field changes direction. Consequently, the nanocomposite materials have a high dielectric constant. The dielectric constant value decreases at high frequencies because the

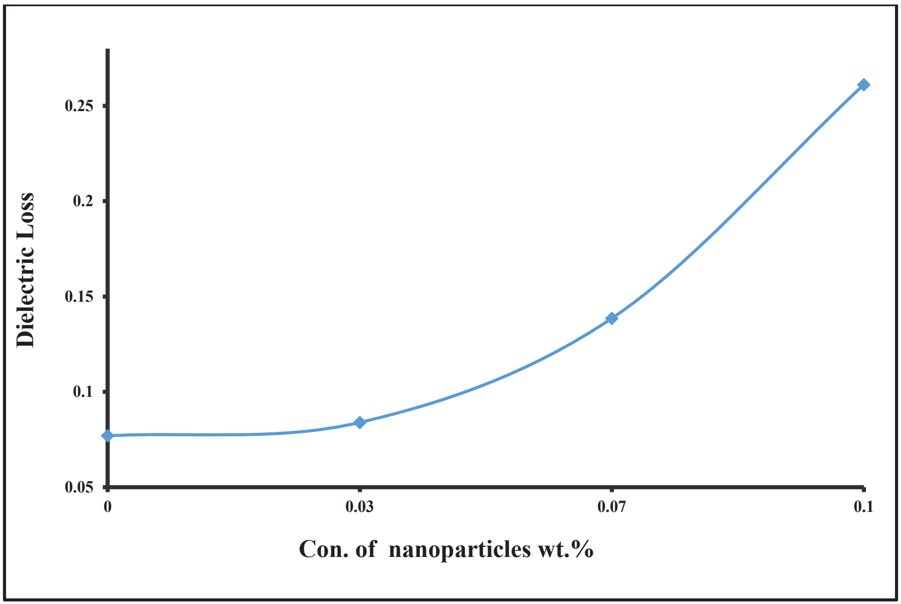

Fig. 4. The concentration of GO nanosheets in the PVA-PVP-SiC-NiO nanocomposite increases the dielectric loss at 100 Hz.

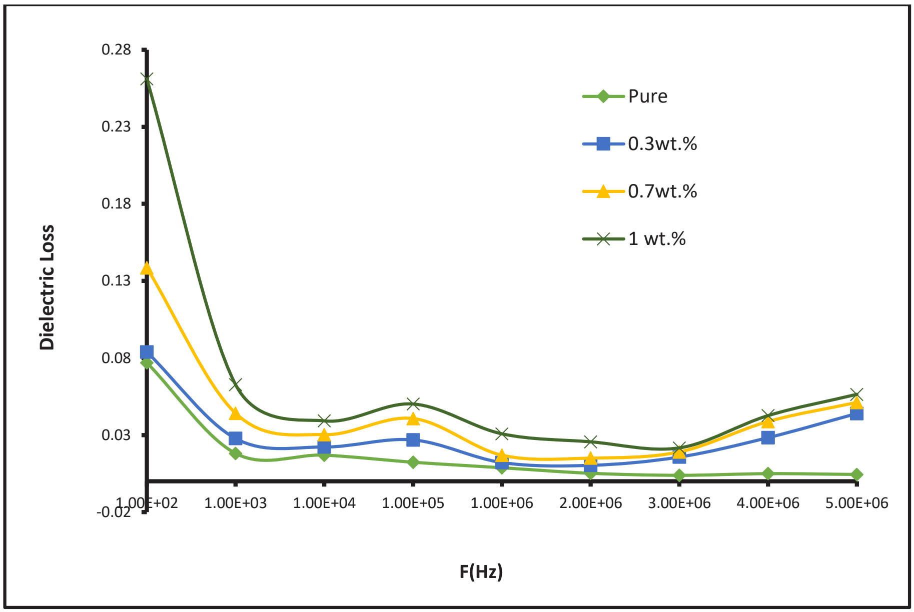

Fig. 5. The PVA-PVP-SiC-NiO nanocomposite's frequency-dependent dielectric loss

electrodes have less time to polarize [25].

At a frequency of 100 Hz, Fig. 6 shows the variation in the alternating current (A.C.) electrical conductivity of the nanomaterials (PVA-NiO) with different concentrations of SiC nanoparticles. The graphic illustrates how the nanocomposites' alternating electrical conductivity rises as SiC nanoparticle concentrations do. This is an increase in conductivity brought about by the addition of more charge carriers as a result of the nanoparticles, which lower the nanocomposite's resistance and raise its electrical conductivity for alternating current [26,27]. Fig. 7 illustrates how the electrical conductivity of the composite nanomaterials (PVA-NiO-SiC) at room temperature changes with frequency. Alternating current's electrical conductivity increases with for a sample of nanomaterials, the frequency of the electric

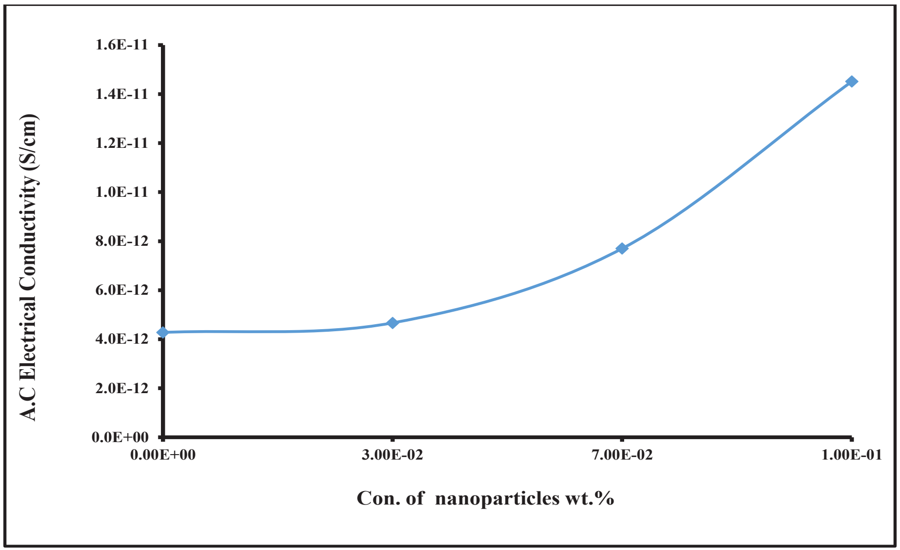

Fig. 6. A.C. electrical conductivity of the PVA-PVP-SiC-NiO nanocomposite at concentrations of (A) CuO at 100 Hz and NiO at 100 Hz.

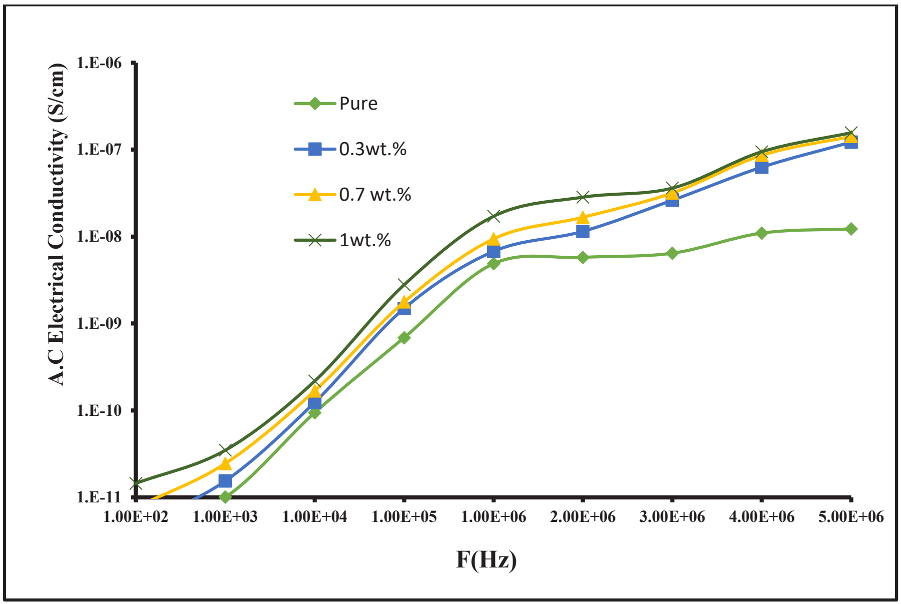

Fig. 7. PVA-PVP-SiC-NiO nanocomposites' frequency-dependent A.C. electrical conductivity

field is increased by charge carrier migration and ionic hopping from the bulk. Due to a greater accumulation of charge at the electrode-electrolyte interface, the quantity of mobile ions and electrical conductivity dropped at low frequencies [28]. Because charge carrier mobility was higher in the high-frequency region, the electrical conductivity of (PVA-NiO-SiC) compounds increased with frequency [29].

SEM was used to examine the effects of ultrasonic nanobubble addition on the structure of pure polymer films (PVA-PVP) and nanocomposites (PVA-PVP-SiC-NiO). Because nanobubbles were dispersed throughout the polymer matrix, the pure sample (A) in Fig. 8 had a uniform texture and surface porosity. Even though there were still a few tiny agglomerations, the bubbles made the particles in the sample with a concentration of 0.3 weight percent more evenly dispersed. At a concentration of 0.7 weight percent, particle aggregates began to form; at 1 weight percent, the agglomerations increased and the surface became significantly rough. An A.

Nevertheless, when NiO was substituted for CuO, the nanobubbles improved dispersion at medium concentrations (0.7 wt%) and produced a homogeneous and dense distribution at high concentrations (1 wt%), demonstrating the usefulness of ultrasound in improving particle embedding within the polymer matrix and decreasing agglomeration [30,31].

Fig. 9 shows pictures of PVA-PVP-SiC-NiO

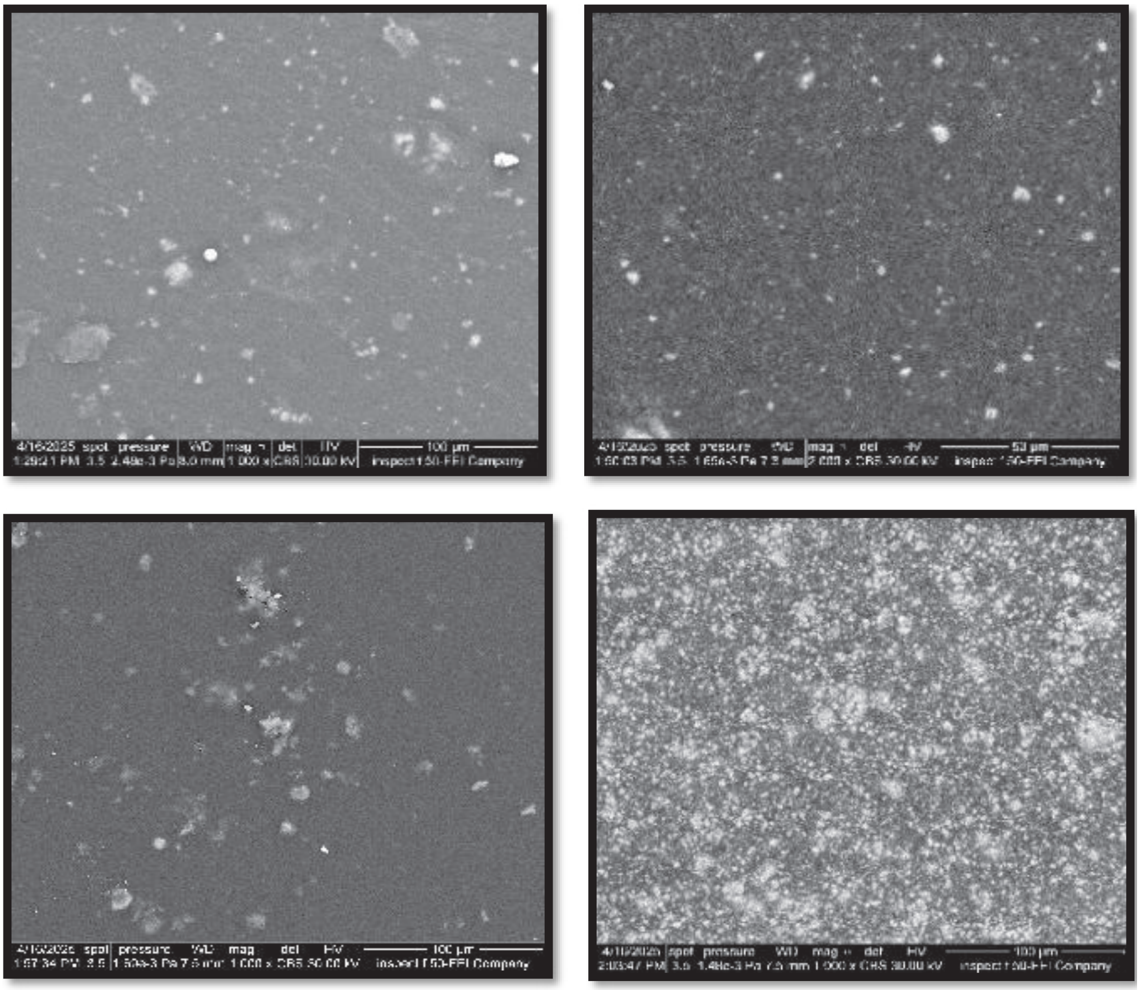

Fig. 8. (PVA-PVP-SiC-NiO) nanocomposites SEM images (A) for the mix (PVA-PVP), (B) for 0.3%wt SiC-NiO, (C) for 0.7wt.% SiC-NiO, and (D) for 1wt.% SiC-NiO.

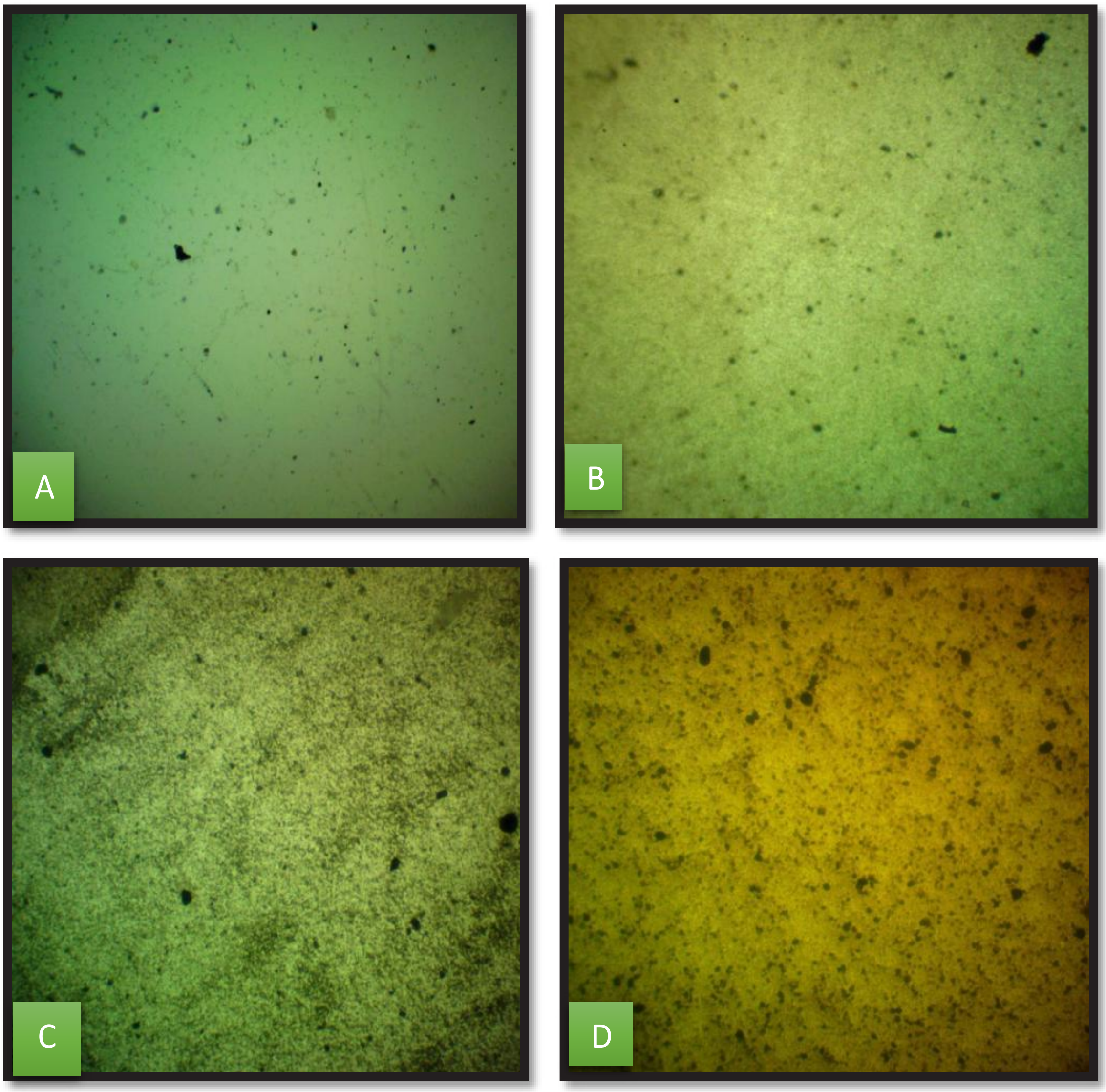

Fig. 9. shows the PVA-PVP-SiC-Nio nanocomposites at 10X magnification. A for (PVA-PVP) and B for 0.3%wt, (PVA-PVP-Sic-NiO), and C for 0.7%wt (PVA-PVP-Sic-NiO), and D for 1%wt (PVA-PVP-Sic-NiO).

nanofilms at ×10 magnification at different concentrations. There are distinct variations between the samples in terms of particle distribution and dispersion because the nanoparticles contributed to the formation of a network within the polymer that facilitates the creation of nanobubbles, enhancing porosity and homogeneity. Direct ultrasonic devices are more effective than mechanical stirring in improving dispersion and inhibiting the agglomeration of nanofibers due to the cavitation phenomenon, which produces a uniform distribution of particles at both the macro and micro levels [31].

CONCLUSION

The study's findings indicate that adding NiO nanoparticles to the PVA-PVP-SiC composite polymer enhances its electrical characteristics. NiO nanoparticles raised the dielectric constant and improved electrical performance stability. The insulating characteristics of the PVA/PVP/SiC/NiO composites improved as the quantity of nanoparticles increased. The electrical conductivity rose when the nanocomposite content hit 1%wt. NiO is therefore advised for usage in capacitors and insulating materials. The results of microscopic pictures like OM and

SEM showed that the application of ultrasound increased the dispersion of nanoparticles within the polymer matrix. This occurred as a result of the microscopic photos' adequate structural homogeneity.

The scanning electron microscope's pictures also showed an improvement in surface uniformity and a reduction in agglomeration. This suggests that the selected methods are effective in enhancing the optical and structural characteristics of nanomaterials, expanding their use in cutting-edge optical and electrical devices.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

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