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REGULAR ARTICLE

Assessing the Electrical and Thermal Characteristics of Prepared PVA-Ag NPs Composite

Wissam A. Hussian[1,*] ✉, Shahad A. Hatam[1,†], Mustafa H. Omar[2,‡]

[1] *The General Directorate for Education in Diyala, Diyala, Iraq*
[2] *Department of Materials Engineering, College of Engineering, University of Diyala, Diyala, Iraq*

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In this research, the thermal and electrical characteristics of a polymer matrix composite with polyvinyl alcohol as a constituent (PVA) integrated with nanoscale silver particles (Ag NPs) were studied. The PVA-Ag NPs composite samples were meticulously fabricated through the casting process, incorporating varying weight percentages of nanosilver 0 %, 1 %, 3 %, and 5 %. The experimental findings reveal intriguing trends. Specifically, as the applied electric field's frequency increases, the dielectric constant of the PVA-Ag NPs composite decreases while the dissipation factor increases, indicative of altered electrical behavior. Furthermore, there is a noticeable augmentation in AC electrical conductivity. Notably, as the concentration of Ag NPs increases, the composite's dielectric constant and dissipation factor show a proportional rise, unveiling the interplay relationship between silver nanoparticle content and these characteristics.

Keywords: PVA, Ag NPs, Nanocomposites, Dielectric constant, Thermal and electrical properties.

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1. INTRODUCTION

Composite substances, a group of engineering materials are created by mixing a number of different materials in a specific weight or volume ratio. To create a homogeneous material, the supporting components are thoroughly blended with the base material, and each material keeps its original fundamental characteristics [1]. It is important to remember that the base material and the filler material do not fulfill their fundamental functions if there is not a strong relationship between them. If both of these materials are employed, the final material will have properties that differ from the constituent elements' properties, especially for its low weight and high durability. As a result, choosing the elements of a composite material is crucial for their final properties to complete one another while still having significantly different properties [2]. The enhanced physical, thermal, and other properties of the Nanocomposites can be manufactured by using easy and affordable methods, and their properties are superior to those of traditional micro scale composites. Materials with unique colors, electrical qualities, high mechanical strength, and low weight, and superior dependability in harsh environments are needed for a variety of energy-efficient applications varying from electronic packages to automobile or aircraft components. An electronic package polymer composite needs to be electrically insulating, but an aircraft component may need to be electrically conductive to dissipate charge from lightning strikes. [3, 4].

Water can dissolve the crystalline vinyl polymer known as polyvinyl alcohol (PVA). It is a long-chain molecule with hydroxyl groups (-OH) bound to the carbon atoms. Several noteworthy properties of polyvinyl alcohol (PVA) include its exceptional optical transmission, non-corrosiveness, biodegradability, biocompatibility, and chemical and thermal stability [5].

The hydrogen bonding between PVA and other substances is facilitated by the presence of -OH groups on the carbon backbone of PVA. The formation of complexes or the blending of PVA with other polymers are facilitated by these bonds. [6-8]. Polyvinyl alcohol (PVA) is very desirable due to its cost-effectiveness, widespread availability, abundance of volatile functional groups, hydrophilic nature, exceptional charge storage capability, and significant dielectric strength [9-11].

2. EXPERIMENTAL WORK

The (PVA) matrix and nano silver particle filler are the materials used in this work. Distilled water was used to dissolve the (PVA) and remove aggregates and ensure a better dispersion in the solvent, the nanosilver was added to the polymer matrix in various weight percentages (0 %, 1 %, 3 % and 5 %) by weight. The nanocomposites were prepared using the casting technique. Once solvent-free nanocomposites were obtained, the solutions were placed in dry glass Petri dishes to allow the evaporation process to occur at room temperature. Circular disc samples were then prepared with smooth surfaces and positioned between two parallel plated electrodes in order to use a (LCR) meter (Agilent Impedance Analyzers 4294A) to analyze the samples' dielectric properties. The computer was linked to the (LCR) meter,

* Correspondence e-mail: wissamphysics@yahoo.com
† shahad_199411@yahoo.com
‡ mustafahassan550@gmail.com

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and data was gathered in relation to various frequencies. The thermal conductivity was conducted using the Lee's Disc method at frequencies ranging from (50 Hz) to (5 MHz) at room temperature.

The dielectric constant, was determined utilizing equation (1), which provides a capacitor's capacitance ratio filled with dielectric to a capacitor with no dielectric (C0). Equation (2) was used to calculate the dissipation factor (tan) using the dielectric constant that was measured and dielectric loss, whereas equation (3) was used to determine the AC. electrical conductivity (AC) subsequent to replacing the measured values [12].

$$\varepsilon^{-} = \frac{c_p}{c_o} \quad (1)$$

$$\tan\delta = \frac{\varepsilon^{''}}{\varepsilon^{-}} \quad (2)$$

$$\sigma_{AC} = w\varepsilon''\varepsilon_0 \quad (3)$$

The thermal conductivity was determined using Lee's disk method using equations (4) and (5), respectively:

$$K = e\left[T_A + 2/r\left(dA + 1/4ds\right)T_A + 1/2rds \cdot T_B\right] \times \times\left(T_B - T_A\right)/ds \quad (4)$$

$$IV = \pi r^2 e\left(T_A + T_B\right) + +2\pi re[d_A T_A + ds1/2\left(T_A + T_B + d_B T_B + d_C T_C\right] \quad (5)$$

which T_A, T_B, T_C represent the temperatures between the disks *A*, *B*, and *C* and room temperature; *ds*, *dC*, *dA*, and *dB* represent the thicknesses of the sample, disks *A*, *B*, and *C*, in that order; *V* represents the potential difference across the heater; *I* represents the current flowing through it; and e represents the energy emitted from the surface (measured in joules).

3. RESULTS AND DISCUSSION

3.1 AC Electrical Characteristics

PVA-Ag NPs composites' AC electrical characteristics were investigated at frequencies between 100 Hz and 5 MHz. One of the most crucial aspects of an AC system. Figure (1) demonstrates that for all samples, the PVA-Ag NPs nanocomposites' frequency increases cause the dielectric constant decreasing. It can be also observed that at low frequencies, all samples had high values of higher frequency, and the dielectric constant, there is a significant and abrupt decrease in the dielectric constant values. This can be accounted for the reality that at low frequencies, there is enough time for the molecules to organize and move in the direction of the electric current flowing between the two poles. Additionally, the polarity of the electrodes and the existence of interfaces between the Ag and the polymeric material are to blame for the large values of the dielectric constant at low frequencies. According to the characteristics of the sample, the polarization that results from the electrodes closely relates to the formation of the charge of the sample between the two electrodes [13, 14].

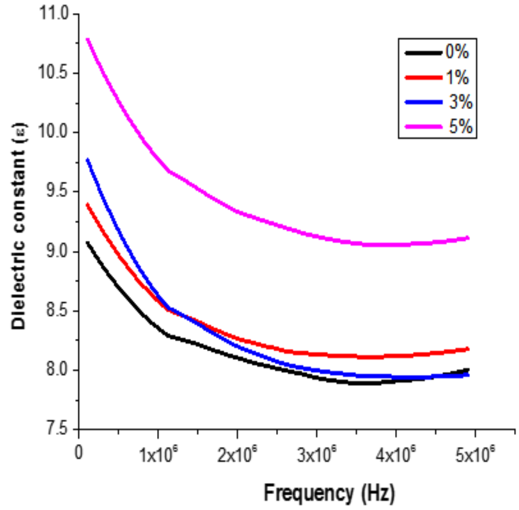

Fig. 1 – Variation of PVA-Ag NPs' Dielectric Constant with different frequencies

Figure (2) illustrates the impact for various concentrations of nano silver particles, frequency's impact on the dissipation factor of PVA-Ag NPs composites. The dissipation factor declines as frequency rises, which is caused by a reduction in the number of dipoles in nanocomposites. According to Figure (2), an increase in the weight percentages of nanosilver particles is what causes the electrical conductivity of the polymer matrix to increase with an increase in the number of electrons in nanocomposites [15, 16].

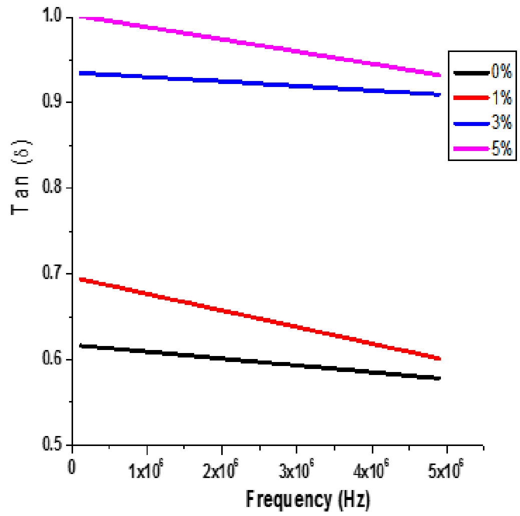

Fig. 2 – variation of PVA-Ag NPs' Dielectric Loss with different frequencies

Figure 3 illustrates the impact of frequency on the electrical AC conductivity of nanocomposites. The electrical conductivity in AC systems increases as the frequency of electronic polarization and charge carrier hopping rises. With an increase in nano silver particle concentration, AC electrical conductivity increases [17, 18].

3.2 Thermal Conductivity

Table 1 and Figure 4 depict the relationship between the concentration of Ag NPs and the thermal conductivity coefficient (*k*) (W/m·K).

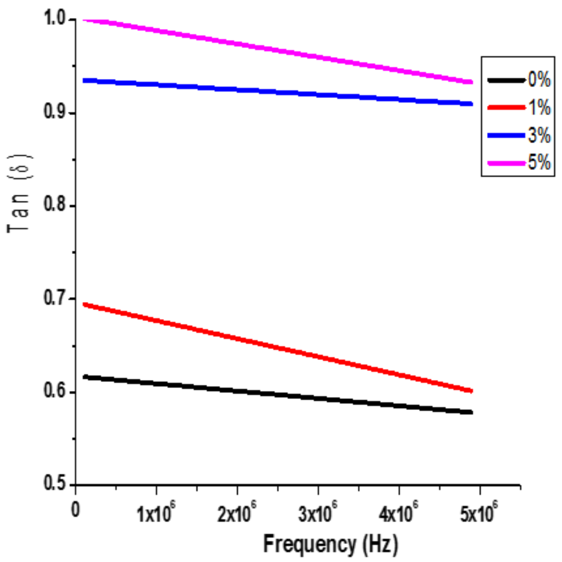

Fig. 3 – Variation of PVA-Ag NPs Electrical Conductivity with different frequencies

It is well known that the matrix material and filler affect the thermal conductivity of composites, so it is expected that the A concentration, which is attributed to the extremely high *k* of Ag NPs, will have a significant effect on pure (PVA)'s thermal conductivity. The figure demonstrate that as Ag NPs concentration is increased, thermal conductivity slightly increases. This slight increase in thermal conductivity is caused by the added nanosilver particles [19, 20].

Table 1 – Thermal conductivity coefficient's value (*k*) (W/m·K)

NPs with PVA-Ag	Coefficient of thermal conductivity (*k*) (W/m·K)
0 %	1.73×10^{-3}
1 %	2.05×10^{-3}
3 %	2.19×10^{-3}
5 %	2.35×10^{-3}

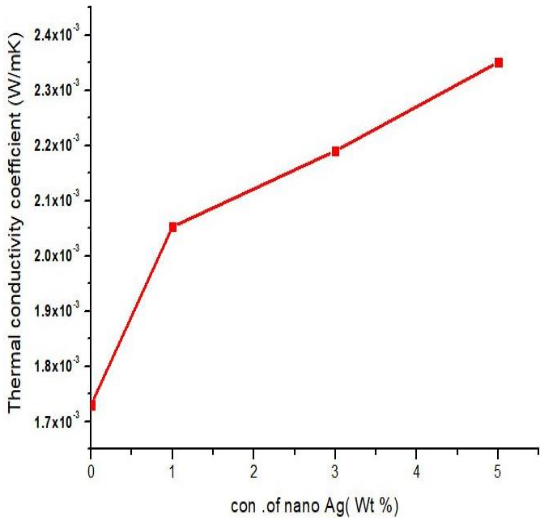

Fig. 4 – Mariation of thermal conductivity with Ag NPs

4. CONCLUSIONS

Solution casting was used to successfully prepare PVA-Ag NPs Composites. The polymer composites' dielectric properties were evaluated. With increasing frequency, the dissipation factor and dielectric constant declined. This is because of the frequency-dependent electronic, ionic, dipolar and surface charge polarizations. It is possible that the space charge polarization that develops at grain boundary interfaces is the cause of the large values of dielectric constant at low frequencies. The increase in AC electrical conductivity, dielectric constant, dielectric loss, and thermal conductivity of PVA-Ag NPs is directly proportional to the weight percentage of Ag NPs. As the weight percentage of Ag NPs increases, all these dielectric parameters also increase. This results in a decline in the dielectric constant and dissipation factor of PVA-Ag NPs, along with an increase in AC electrical conductivity, as the frequency of the applied electric field-rises.

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Оцінка електричних і теплових характеристик готового композиту PVA-Ag з наночастинками срібла

Wissam A. Hussian[1], Shahad A. Hatam[1], Mustafa H. Omar[2]

[1] *The General Directorate for Education in Diyala, Diyala, Iraq*
[2] *Department of Materials Engineering, College of Engineering, University of Diyala, Diyala, Iraq*

У статті представлені результати дослідження теплових та електричних характеристик полімерного матричного композиту на основі полівінілового спирту (ПВС), інтегрованого з нанорозмірними частинками срібла (Ag NPs). Композитні зразки PVA-Ag з наночастинками срібла були виготовлені в процесі лиття, включаючи різні вагові відсотки наносрібла 0%, 1%, 3% і 5%. Експериментальні результати показали, що зі збільшенням частоти прикладеного електричного поля діелектрична проникність композиту PVA-Ag NPs зменшується, а коефіцієнт дисипації збільшується, що вказує на зміну електричної поведінки. Крім того, спостерігається помітне збільшення електропровідності змінного струму. Примітно, що зі збільшенням концентрації наночастинок Ag діелектрична проникність композиту та коефіцієнт дисипації демонструють пропорційне зростання, що свідчить про взаємозв'язок між вмістом наночастинок срібла та вище описаними характеристиками.

Ключові слова: PVA, Наночастинки Ag, Нанокомпозити, Діелектрична проникність, Теплові та електричні властивості.