

RESEARCH PAPER

A Novel Eco-Friendly Resin/Ag₂O Nanocomposite: Its Physico-Chemical and Antibacterial Studies as a Multifunctional Promising Material

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ARTICLE INFO

Article History:

Received 19 July 2025

Accepted 10 October 2025

Published 01 January 2026

Keywords:

Ag₂O

Antibacterial

Nanocomposites

Physical Properties

ABSTRACT

This text dives into an intriguing process really revolves around creating, characterizing, and testing this unique silver-based hybrid nanocomposite, Ag₂O/resin. To prepare the resin, we use an organic framework from the leaves of cheap, accessible and common medicinal plants. Silver oxide nanoparticles were then blended with the resin to form the composite. Various spectroscopic and microscopic techniques were applied to study surface morphology and functional sites in characterizing the ends of the prepared composite.

How to cite this article

Aysa N. A Novel Eco-Friendly Resin/Ag₂O Nanocomposite: Its Physico-Chemical and Antibacterial Studies as a Multifunctional Promising Material. J Nanostruct, 2026; 16(1):82-88. DOI: 10.22052/JNS.2026.01.009

INTRODUCTION

The interest in resin/Ag₂O nanocomposites with improved physical properties and antibacterial characteristics is becoming ever more important. The silver oxide nanoparticles within the resin composites demonstrated effective control of *Streptococcus mutans* with good promise. Antibacterial activity of silver nanoparticles in these composites varied with the concentration [2]. Primarily, due to the advances in nanotechnology, these materials contain metals, specifically silver, whose activity is enhanced due to their high surface-to-volume ratio and peculiar crystallographic structure [3]. Mixing silver particles at nanoscale with various kinds of materials like silica, carbon, polysaccharides, resins, inorganic nanoparticles, and chitosan gives us silver nanocomposites [4]. Metal-polymer nanocomposites possess higher antibacterial properties than their individual

nanoparticles [5]. For example, by reinforcing silver oxide nanoparticles into polymer films, they become antibacterial agents that can be used to develop antibacterial materials such as textiles and coatings. In dentistry, we can enhance the durability and more sustained action of resin-based materials by introducing bioactive agents such as quaternary ammonium compounds (QAM) and remineralizing fillers such as calcium fluoride or amorphous calcium phosphate [6]. This study looks into the new resin/Ag₂O nanocomposites in terms of their physical and antibacterial properties. More specifically, we can fabricate Ag₂O/resin nanocomposites using well-documented techniques and characterize them using several microscopic and spectroscopic methods [7].

Assummarized, resin plays a vital role in the world of nanocomposites since its diverse characteristics

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are key to their evolution. Through manipulating various fillers and nanoparticles, the antibacterial and physical properties of resin formulations can equally boost considerably [6], facilitating their wide utilization in different domains such as water filtration, dental caries, and restorative dental composite resins. The incorporation of diverse types of functional materials, amongst which are metal oxides, calcium fluoride/phosphate particles, silver nanoparticles (AgNPs)—all in its resin—help create materials that are multifunctional in their own right, with significantly enhanced antibacterial properties. This alteration in the remineralization/demineralization process affects the creation of smart materials that acclimatize to a myriad of conditions. There exist many studies on the antimicrobial effects of silver nanoparticles incorporated inside polymer nanocomposites against various pathogens. Research also proposed indications that the incorporation of AgNPs into a polymer matrix during processing is effective at fighting multidrug-resistant microorganisms. Moreover, a blend of polymers containing silver oxide NPs helps to prevent particle clumping, enhancing the antibacterial efficiency by controlling the release of Ag⁺ cations, and thwarting the growth or reproduction of microorganisms on any surface. This particular path could unravel unprecedented opportunities in electrophysical materials and self-healing electronics for biomedical applications,

for example, using BS polymers with silver oxide NPs [5-7]. Not long has the emergence of silver nanocomposites as antimicrobial agents started to evoke considerable interest. Silver nanoparticles are being mixed with quite a few materials which have ranged from carbon and polysaccharides to silica, chitosan, inorganic nanoparticles, etc., to give birth to new resin/polymer-based systems [9]. Research shows that silver nanoparticles have a broad spectrum of antiviral, antifungal, and antibacterial activities. The antibacterial activities are further intensified when laden onto composites, such as adhesive for orthodontic treatment or resin for posterior restorations. Such silver nanocomposite formulations are used to provide some antibacterial properties to their dental composite resins, improving their physical properties, which must remain biocompatible [10]. Incorporating Ag₂O nanoparticles in orthodontic composite resins shows improved mechanical strength and increased bacteria-killing efficiency against *Streptococcus mutans* and any other bacteria that might also cause dental caries. To sum it up, the good news is that the antibacterial aspect of silver nanoparticles stands well in their equally beneficial use and compatibility with different matrices in antimicrobial technology implemented for dentistry. Keeping in mind, however, the environmental threat that Nanotechnology may pose, strict guidelines should regulate the use of these very promising nanocomposites.

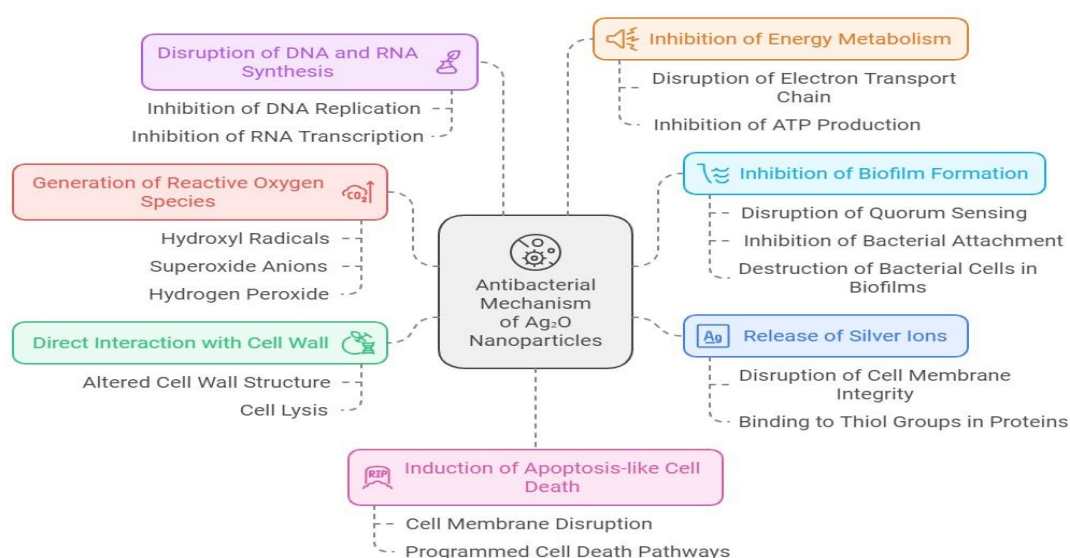


Fig. 1. The main mechanisms of antimicrobial activity of Ag₂O nanoproducs.

RESULTS AND DISCUSSION

Materials and Methods

On-demand synthesis of Ag₂O (silver oxide) nanoparticles using *Azadirachta indica* (neem) leaf extract in green synthesis. It is widely believed that the juice extracted from Neem leaves exerts its medicinal significance due to bioactive molecules constituting, such as flavonoids, terpenoids, and phenolics. Fresh Neem Leaves (*Azadirachta indica*) serve as a potential reducing and stabilizing agent for such nanoparticles. Silver Nitrate (AgNO₃) would act as the precursor for silver ions, while Deionized Water served the purpose to dissolve the chemicals and prepare the extracts.

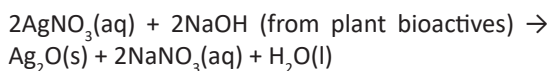
Preparation of Neem Leaf Extract

Cleaning and Gathering: First, thoroughly wash the fresh neem leaves in deionized water to remove any dust, dirt, or contaminants. **Boiling:** Now, take about 50 grams of neem leaves and put them into 200 milliliters of deionized water. Boil and simmer for 20-30 minutes to leach out the active principles. **Filtration:** After boiling, filter the extract through muslin cloth or Whatman filter paper to obtain a clear extract free from insoluble residue. The filtered neem extract will act as a reducing agent during the green synthesis of the AgO nanoparticles. **Cooling:** The neem extract should be allowed to cool to room temperature before use.

Formation of Ag₂O Nanoparticles

Dissolve a suitable quantity of silver nitrate (AgNO₃) in deionized water to make a 0.01 M solution. Shake the container thoroughly until all the solid silver nitrate dissolves. Add the neem extract slowly dropwise by continuously stirring the silver nitrate solution with a magnetic stirrer. Keep stirring this mixture at room temperature for about two to three hours, during which time the bioactive compounds in neem extract convert the Ag⁺ ions into Ag₂O nanoparticles. The solution will start changing to brown or yellowish-brown as the silver oxide nanoparticles are formed. At the end of the reaction, the Ag₂O nanoparticles will sediment from the solution. For this, centrifuge the mixture for 15 minutes at a speed of 4000-6000 rpm. Wash the nanoparticles afterward two to three times with deionized water to remove any residual silver nitrate or impurities. Finally, dry the cleaned Ag₂O nanoparticles in a drying oven at a temperature between 50 and 70 °C for several

hours or overnight to remove excess moisture. This will condition the Ag₂O nanoparticle powder for characterization and use afterward. Reaction Equation [13]:



Characterization

The characterization of Ag₂O nanoparticles becomes of importance in confirming their formation and behavior. Various techniques are in operation to evaluate the spectroscopic characteristics of the Ag₂O/resin composite, thereby gaining an insight into its structural and chemical natures. (Fig. 2 A) show the absorption peak lies within the range of surface plasmon resonance (SPR), characteristic of silver-based nanoparticles. The higher the absorbance, the greater the particle concentration or size. One such technique offers very useful information regarding the crystalline nature of the composite, namely X-ray diffraction (XRD) (Fig. 2 B). It reveals the crystal structure, phase purity, and particle size of the Ag₂O nanoparticles embedded in the resin matrix. Such information is critical for a complete understanding of the composite's physical properties and antibacterial activity [14]. Observed peaks: Distinct diffraction peaks are observed at (111), (200), (220), and (311) planes. These peaks match the standard diffraction pattern of crystalline Ag₂O, confirming the crystalline nature and purity of the sample without significant impurities. Would also be of significance concerning the spectroscopic characterization is the Fourier-transform infrared spectroscopy or FTIR. With respect to the structural, functional groups, and chemical identification of composites, FTIR has its own way of confirming that presence within the resin matrix of Ag₂O nanoparticles and probably can identify some specific chemical bonds from the FTIR spectra. This is of great importance when assessing the antipathogen properties stemming from these functional groups within the composite material [9]. It is essential to first understand regarding the nanocomposite's morphology for understanding the structure and expected application of the Ag₂O/resin nanocomposite. The incorporation of silver nanoparticles into the resin matrix could really change the overall morphology of the nanocomposite. The surface morphology of the composite with regard to the

dispersion of Ag₂O nanoparticles in resin can be assessed by SEM. This would give an insight into the distribution, agglomeration, and clustering of these nanoparticles, thereby affecting some of the properties of the material [15]. Scanning electron microscopy (SEM) (Fig. 2 C) is a great tool to obtain high-resolution images on surface topography. It gives crucial information relating to the morphology and microstructure of nanocomposites. It can capture important findings about the distribution and dispersion of the Ag₂O nanoparticles within the matrix of the resin. The nanoparticles appear to be porous and aggregated. This porous morphology enhances the surface area, which can be beneficial in catalytic, environmental, or biomedical applications. (Fig. 2 D) show that 684 cm⁻¹: Corresponds to Ag–O bond vibrations. 1042 and 1376 cm⁻¹: Attributed to C–O or OH-related vibrations, likely from the resin. 1630 cm⁻¹: Indicates bending of O–H or C=C vibrations. 2360 cm⁻¹: Typically associated with atmospheric CO₂. This confirms the presence of both organic resin components and Ag₂O

functional groups. That means this will give some important indications about general homogeneity and structure of nanocomposite material [1]. These techniques are useful to investigate homogeneity, modelling particle distribution and agglomeration, and polymeric-strength testing of resin/Ag₂O nanocomposites. They also expose some defects and anomalies that could affect the performance and antimicrobial properties of these advanced materials [2].

Antibacterial Study of Ag₂O (Silver Oxide) Nanoparticles Embedded in Resin against Pathogenic Bacteria

Collect bacterial strains like *S. aureus*, *S. pyogenes*, *E. coli*, *P. aeruginosa*, *K. pneumoniae* from clinical isolates or from a culture collection. Inoculate these bacterial strains into nutrient broth and incubate freshly prepared cultures for about 18 to 24 hours at 37 degrees Celsius. After incubation, measure inhibition zone surrounding the clear area around the disc to assess antibacterial activity. Compare the inhibition zone of Ag₂O-resin

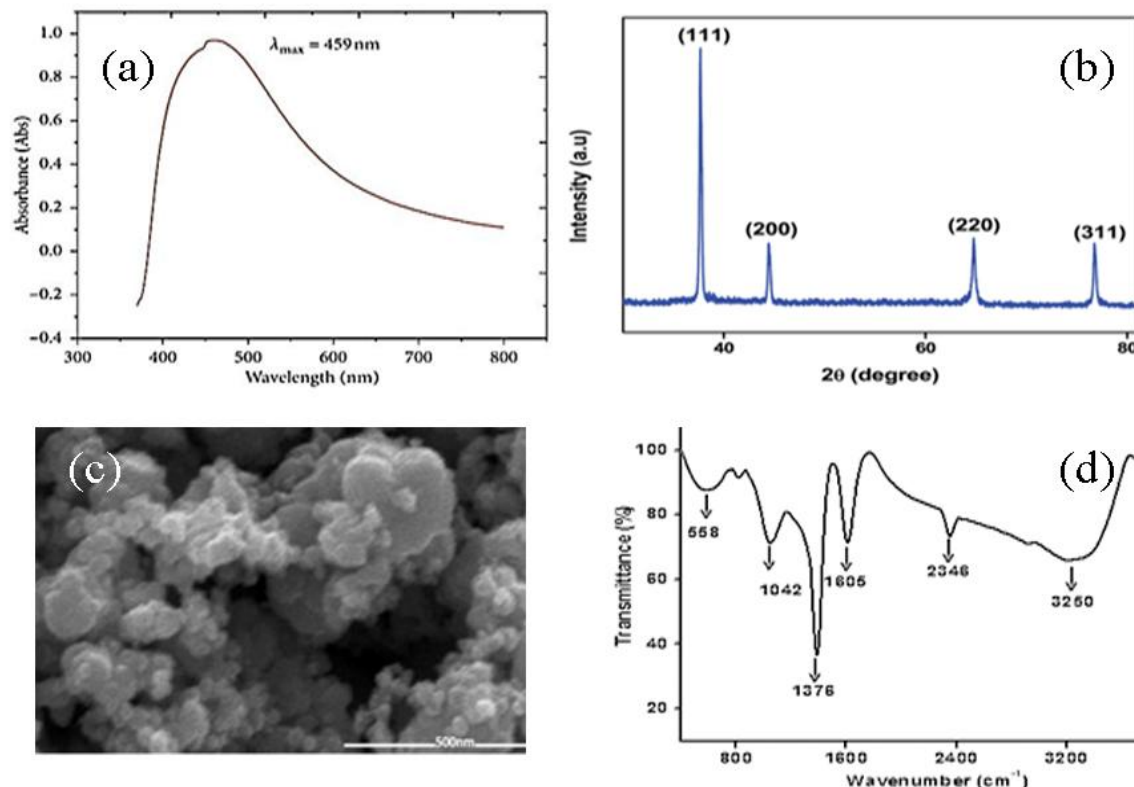


Fig. 2. characterization of Ag₂O/Resin nanocomposites A (UV-vis absorption spectrum), B (X-ray Diffraction (XRD) Pattern), C (Scanning Electron Microscopy (SEM) Image), D (Fourier Transform Infrared Spectroscopy (FTIR) Spectrum).

discs with that of the positive control treated with antibiotics and the negative control using only resin. The stronger the inhibitory action, the greater the area of inhibition. Investigations have proved that Ag₂O nanoparticles exhibit activity against both Gram-negative (*E. coli*, *P. aeruginosa*, *K. pneumoniae*) and Gram-positive (*S. aureus*, *S. pyogenes*) species. Interestingly, perhaps due to their thinner peptidoglycan layer, Gram-negative bacteria are probably more susceptible

to Ag₂O nanoparticles. The resin matrix can also give a prolonged antibacterial activity as the nanoparticles Ag₂O are gradually released from it.

Antibacterial Activity Evaluation

Bacterial cultures of *S. aureus*, *S. pyogenes*, *E. coli*, *P. aeruginosa*, and *K. pneumoniae* can be isolated either from clinical specimens or from a culture collection. They can be revived by inoculating nutrient broth and incubating at 37°C

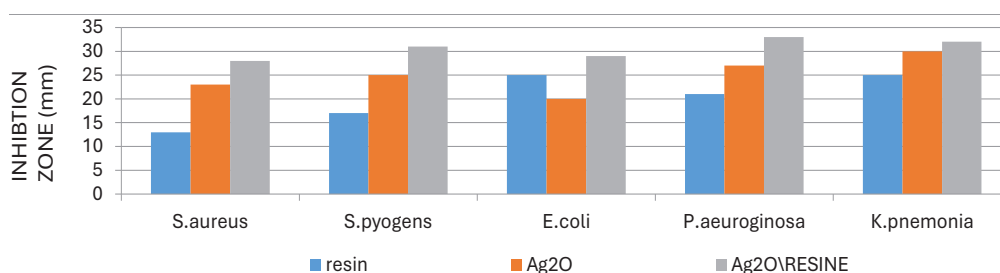


Fig. 3. compartment between the three-material used at high concentration (80%).

Table 1. shows the effect of different concentrations of resin against different bacteria.

Bacteria	Resin			
	%20	%40	%60	%80
<i>S. aureus</i>	0	11	12	13
<i>S. pyogenes</i>	0	11	15	17
<i>E. coli</i>	20	23	25	25
<i>P. aeruginosa</i>	0	0	10	10
<i>K. pneumoniae</i>	21	23	25	26

Table 2. shows the effect of different concentrations of Resin\Ag₂O nanocomposites against different bacteria.

Bacteria	Resin\Ag ₂ O nanocomposites			
	20%	40%	60%	80%
<i>S. aureus</i>	20	21	25	28
<i>S. pyogenes</i>	15	17	25	27
<i>E. coli</i>	13	18	18	20
<i>P. aeruginosa</i>	19	19	21	21
<i>K. pneumoniae</i>	17	21	22	25

Table 3. shows the effect of different concentrations of Ag₂O nanocomposites against different bacteria.

Bacteria	Ag ₂ O			
	%20	%40	%60	%80
<i>S. aureus</i>	19	22	23	23
<i>S. pyogenes</i>	22	23	23	25
<i>E. coli</i>	16	17	19	20
<i>P. aeruginosa</i>	18	20	24	27
<i>K. pneumoniae</i>	18	19	23	30

Table 4. the mechanical study of both resin and nanocomposites.

Mechanical properties	Resin	Ag ₂ O\Resin nanocomposites
Tensile strength (Mpa)	98	210
Tear resistance (KN\m)	47	324
Young modulus (Gpa)	5	65
Elongation %	4	1.5
Hardness (shore D)	73	108

for about 18 to 24 hours. Antibacterial activity can then be evaluated by measuring the zone of inhibition, which is a clear area surrounding the disc. Comparison of the zone of inhibition from Ag₂O-resin discs with that of negative control. So, these evaluations for antibacterial action will encourage a better understanding of the antibacterial mechanisms and effectiveness of these resin/Ag₂O nanocomposites against Gram-positive and Gram-negative bacteria, for instance: *Staphylococcus aureus* and *Escherichia coli*. They need to be performed according to the standard guidelines, for which the following are provided. All test are performed in such a way as to avoid significant interference due to the resin itself and will have an antibiotic as positive control. Wider zones of inhibition mean more activity, of course. Interestingly, Ag₂O nanoparticles were reported as effective against both Gram negatives (*E. coli*, *P. aeruginosa*, *K. pneumoniae*, etc.) and Gram-positive (*S. aureus*, *S. pyogenes*, etc.) bacteria. Gram-negative bacteria might have higher susceptibility to Ag₂O nanoparticles, which might be due to their relatively thinner peptidoglycan layer. The nanoparticles will be able to offer sustained antibacterial activity through their release from the resin matrix [16-18].

Besides its strong antibacterial activity, this composite showed good adsorption characteristics, thereby making it suitable for application in water purification. With regard to silver-based nanocomposites reported in several studies, the resin/Ag₂O nanocomposite may have an important antibacterial effect against a broad spectrum of bacteria; however, for a comprehensive understanding of their mode of action and efficacy against bacteria, further appropriate testing, as presented in the Tables 1-3, is required.

The finding shows that the combination of Ag₂O and resin exhibit high inhibition zone for all bacteria. This broad activity can be explained by the release of silver ions (Ag⁺) from Ag₂O

nanoparticles, which have been shown to disrupt bacterial cell membranes, cellular respiration, and enzyme activities. Table 4 show the mechanical properties of prepared nanocomposites that match the desired applications.

CONCLUSION AND FUTURE DIRECTION

The assessment of the combined resin and silver oxide nanoparticles as a nanocomposite revealed some promising antibacterial properties. Effectively, this particular system may find a way to various industries, opening the doors for completely new electronic devices and sporting gear. The antibacterial activity occurs because of the controlled release of Ag⁺ ions from the silver nanoparticles dispersed in the polymer matrix, which, in turn, prevents the nanoparticles from clumping together. For future directions, further study could focus on the mechanical properties of these composite materials at different temperatures and with prolonged use. Studies should also address the regeneration of these composites, the sizes of the nanoparticles and the tendency of agglomeration, and their possible applications in biomedicine, agriculture, and environmental science. Dentistry needs to embark on more studies to produce and evaluate restorative materials that can prevent adhesion and biofilm formation. These nanoparticles, endowed with antimicrobial properties, could result in materials possessing strong antibiofilm capabilities, aiding the cavity prevention scheme. Less is out in the state of art of antimicrobial nanomaterials for future development of antibacterial dental therapeutics. Metal oxide nanoparticles, in general, are receiving attention for antibacterial applications. Very fascinating new nanocomposite systems still on the drawing board show extraordinary enhancement in mechanical and antimicrobial properties. To qualify these composite systems for various applications, cytotoxicity and related long-term effects on eukaryotic cells still need extensive research.

ACKNOWLEDGMENT

This work was supported by the college of pharmacy of the university of Babylon. Professor Rasha Hadi Saleh is acknowledged for helping us with revision of the manuscript.

CONFLICT OF INTEREST

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

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