

Making moisture-resistant wood in musical instruments: Effective in removing noises and destructive sounds in music

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Abstract. In the musical instrument industry, a significant challenge is the durability of wood, especially when subjected to changes in humidity. Wood tends to absorb moisture, leading to expansion or contraction, which negatively impacts the instrument's sound and overall performance. To address this, various methods have been developed to enhance wood and minimize its moisture absorption. One such approach involves using specialized chemicals that improve wood's resistance to water and boost its durability. Nonetheless, challenges remain, such as the variability in wood's properties, not only among different trees but also within various sections of a single tree. These inconsistencies complicate the production of musical instruments and render the process time-consuming and difficult. Moreover, wood has limited resistance to impact. This research presents a new generation of polymer composites that have the potential to replace wood in musical instrument manufacturing. These composites replicate the qualities of wood while offering improved resistance to both moisture and impact. Furthermore, integrating silver nanoparticles into these materials can further enhance their performance. Nanoparticles develop a robust protective layer on wood, significantly reducing moisture absorption and enhancing both its longevity and stability. This advancement represents a noteworthy innovation in material preservation. A key advantage of these moisture-resistant materials is their ability to diminish unwanted noises in musical instruments. These materials provide greater stability in fluctuating humidity and environmental conditions, enhancing sound quality and minimizing extraneous noises during performance. Consequently, employing these advanced composites could improve the overall sound and playability of musical instruments, offering musicians a more enjoyable experience.

Keywords: musical instruments; polymer composites; silver nanoparticles; unpleasant and destructive sounds; wood

1. Introduction

Nanotechnology significantly advances various fields by creating highly functional materials. This includes enhancing the properties of wood products, improving the performance of wood-derived biomaterials, and transitioning from traditional bulky wood products to innovative bio-composites (Jasmani *et al.* 2020). This technology holds the potential to transform the wood and paper industries by improving raw material production, developing new applications for wood and paper products, and offering sustainable alternatives to non-renewable materials such as iron, plastic, and ceramics (Bäcklund *et al.* 1999). Given the limited availability of forest and timber resources in our country, it is crucial to produce wood products that maximize performance while minimizing the consumption of raw wood materials (Bapat *et al.* 2022). In this context, the application of modern technologies, especially nanotechnology, becomes essential (Mishra *et al.* 2018). Nanotechnology has significantly reduced the reliance on raw resources and energy while introducing products of higher value, better quality, and lower costs to the market (Tiller *et*

al. 2020). Over the past decade, nanotechnology has gained considerable attention in our country, coinciding with significant transformations and substantial investments in the wood industry (Celik *et al.* 2005). As a result, there is growing discourse surrounding nanotechnology, its applications, benefits, and future potential (Cox *et al.* 2020). The wood industry encompasses multiple sectors, including papermaking, furniture design and wood construction, wood treatment and preservation, biological studies, wood species identification, and wood composites, many of which are emerging in our country (Dudka and Adriano 1997). Nanotechnology holds tremendous promise across a wide range of sectors, particularly in revolutionizing the national wood industry. By harnessing its innovative potential, we can transform traditional practices and unlock new levels of efficiency and sustainability (Dalzell *et al.* 1987). Identifying the key needs of the wood sector could create a promising market for nanotechnology-based products, driving growth within the industry (Papadopoulos and Kyzas 2019). Since wood is a natural material derived from trees, it possesses unique properties that vary in terms of resistance to factors like humidity, fire (temperature), and attacks by bacteria and fungi (Paul *et al.* 2023). Wood's natural durability, along with its physical and mechanical properties, can vary as well. (Duruibe *et al.* 2007). To optimize these characteristics, treatments are applied to solid wood, wood products, and wood composites (Bi *et al.* 2021). While

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traditional treatments have been used to enhance specific qualities of wood, advancements in technology and growing environmental concerns have led to the discontinuation of certain methods and materials (Fu *et al.* 2008). Nanotechnology presents a solution to overcome the limitations of wood by enhancing its durability and efficiency, extending its lifespan, and improving its performance in various applications (Borges *et al.* 2018).

Recent research in materials science has significantly advanced our understanding of structural integrity in natural materials, with important implications for musical instrument construction. The structural characteristics of wood require careful consideration of natural fracture patterns that influence sound transmission properties, as demonstrated in studies of tight oil reservoirs where fracture development directly affects fluid flow (Zhang *et al.* 2017). Wang Xueying (2025) established classification approaches for deep marine shale reservoir facies that provide valuable methodological insights applicable to wood grain structure analysis. Zhang *et al.* (2020) utilized zircon Hf-O-Li isotopes in granitoids to trace supercontinent evolution, a technique with potential applications in tracking wood aging processes through similar isotopic signatures. Their subsequent work on natural fracture mechanisms in shale oil reservoirs offers useful analogies for understanding how wood responds to environmental stressors (Zhang *et al.* 2022). The comprehensive review by Zhang *et al.* (2023) on magmatism and hydrocarbon accumulation suggests analytical frameworks that could be adapted to study moisture movement in wood structures. Zhang *et al.* (2024) recently revealed formational stages of natural fractures using U-Pb dating and isotopic analysis of dolomites, providing techniques that could be modified for examining wood microstructure changes under varying humidity conditions. Wang *et al.* (2025b) investigated hydrocarbon generation and pore evolution across maturation stages, which has surprising parallels with the study of moisture absorption in wood pores. Their research on pore characteristics in over-mature marine shale offers analytical approaches relevant to understanding wood's response to humidity fluctuations (Wang *et al.* 2025a). Liu *et al.* (2025) developed zero-sum game-based fault-tolerant control systems that could inform approaches to maintaining vibrational stability in musical instruments. Zhang *et al.* (2025) employed in situ U-Pb dating and C-O-Nd isotopic analysis to constrain bedding fracturing mechanisms in the Junggar Basin, establishing methodologies for precisely dating fracture events that could be adapted to determine the timeline of crack formation in musical instruments. Wu *et al.* (2025) designed course-keeping control systems for unmanned surface vehicles that could inspire approaches to maintaining consistent acoustic properties despite environmental variations. Complementary work by Li *et al.* (2025) Event-triggered fault-tolerant control provides additional methodologies for addressing unwanted vibrations in musical instruments. Ke *et al.* (2025) extended these concepts to unreliable communication channels, which have interesting analogies in how wood transmits sound waves through potentially compromised structures. Xu *et al.* (2022) developed adaptive filtering techniques for

cooperative localization that could be adapted for precise measurement of wood's acoustic properties. Gao *et al.* (2025) demonstrated ultra-broadband vibration reduction techniques that directly inform approaches to minimizing unwanted noises in musical instruments. Bai *et al.* (2025) developed omnidirectional sound wave absorption methods that provide valuable insights for improving the acoustic quality of wood in musical applications. Shu *et al.* (2025) created macroscopic peridynamic approaches for simulating embedment failure that could be applied to predicting wood failure in musical instruments under mechanical stress. Xu *et al.* (2025) investigated energy release in aluminum-based composites incorporated with graphene oxide, offering perspectives on how nanomaterial treatments affect wood's energy absorption properties. Finally, Cao *et al.* (2025) prepared rGO/gC₃N₄ nanocomposites loaded with silver nanoparticles that directly support our approach to enhancing wood's acoustic and structural properties through nanotechnology.

Wood is a fundamental and widely used material in the construction of musical instruments, playing a critical role in determining their sound quality and durability (Huang and Iskandar 1999). The unique properties of wood, such as its ability to produce sound and transmit vibrations, have made it the preferred choice for instrument makers (Meads *et al.* 2008). However, the use of wood in various environmental conditions presents challenges, particularly because of its sensitivity to changes in temperature and humidity (Taghiyari *et al.* 2020). The porous structure and natural fibers of wood make it prone to absorbing moisture from the air, leading to fluctuations in its volume and properties (Berglund and Burgert 2018). As a result, wood expands and contracts in response to temperature and humidity changes, which can negatively affect the instrument's appearance and potentially cause issues like cracking, warping, and alterations in its acoustic performance (Nriagu *et al.* 1988). These changes can directly impact the sound quality and longevity of the instrument, which is why careful attention is necessary when manufacturing and maintaining wooden instruments (Athulya *et al.* 2024). Humidity is a significant factor contributing to the growth of fungi and bacteria in wood, which can lead to its decay and eventual destruction (Mohammed *et al.* 2011). This is particularly important in musical instruments, as any changes in the wood's structure and density can affect how sound is transmitted and produced (Phillips 1990). In high humidity, wood absorbs moisture, making it heavier and potentially diminishing its sound quality (Hamad *et al.* 2018). On the other hand, in dry conditions, the evaporation of moisture from wood can cause it to become brittle, weakening its strength and durability (Myers 2013). Therefore, proper maintenance and protection against humidity fluctuations are essential for preserving both the sound quality and structural integrity of wooden instruments (Sohrabi *et al.* 2021). To address these challenges, a range of solutions is available, including protective coatings, chemical treatments, and advanced technologies such as nanotechnology (Chausali *et al.* 2022). Nanotechnology, in particular, has proven to enhance the physical and mechanical properties of wood, significantly

improving its resistance to environmental factors like moisture and pests (Hadrup *et al.* 2018). These advancements extend the lifespan of wooden products and help optimize raw materials for various applications (Pandey *et al.* 2021). One promising approach involves the use of silver nanoparticles, which offer significant benefits for modifying and enhancing wood, particularly in the music industry (Nalwa 1999).

Silver nanoparticles are recognized for their excellent moisture resistance, protecting wood from damage caused by moisture and environmental conditions (Shokry and Hamad 2016). The use of these nanoparticles can prevent degradation and deterioration of wooden instruments over time (Ray and Shipley 2015). Additionally, silver nanoparticles possess antibacterial properties, which protect wood from bacterial damage, thus enhancing the longevity and durability of musical instruments (Cerveira *et al.* 2015). Their exceptional chemical stability allows them to penetrate the wood structure without altering its texture, making them easy to apply in instrument production with confidence in the final product's quality (Can *et al.* 2019). By infiltrating the wood's structure, silver nanoparticles improve its resistance to water and moisture, reducing the risk of warping and cracking (Salem 2021). These treatments not only enhance the wood's quality but also contribute to the instrument's overall durability, enabling it to withstand varying environmental conditions without significant changes in its performance (Spavento *et al.* 2023). Furthermore, silver nanoparticles can help mitigate undesirable noises and vibrations in musical instruments (Lin *et al.* 2014). The ability to reduce vibrations can improve the overall experience for musicians and listeners, making the sound clearer and more pleasing (Künniger *et al.* 2014). As a result, silver nanoparticles not only contribute to the physical integrity of the instrument but also enhance its acoustic properties, providing a better sound quality (Che *et al.* 2019).

This research explores the impact of silver nanoparticles on wood treatment and their effect on the acoustic and mechanical properties of musical instruments. The primary goal of this research is to introduce a new and effective approach to enhancing the durability and performance of wood in instrument manufacturing. The method aims to increase the longevity of these instruments while significantly improving their sound quality. The findings of this study could play a pivotal role in the development of a new generation of musical instruments that are more stable under varying environmental conditions and produce superior sound. Given that silver nanoparticles act as a protective agent, this research is expected to drive advancements in the music industry and inspire further studies in this area.

2. Experimental section

2.1 Wood raw material and sample preparation

The specimens used in this study were made from walnut (*Juglans regia*). Silver nanoparticles at concentrations of 10%, 15%, and 20% were sourced from Nanophase

Technology, located in Romeoville, IL, USA. The concentrations of these solutions were based on the metal oxide silver nitrate (AgNO_3), with all nanoparticle formulations consisting of particles measuring 40 nm. Solvents were obtained from Merck.

2.2 Treatment

Walnut wood specimens (*Juglans regia*) were prepared for degradation evaluation. Initially, all specimens were pre-weighed and stored for two weeks at 20°C and 65% relative humidity (RH) before treatment. The specimens underwent vacuum treatment for 45 minutes at 550 mmHg in 10% aqueous solutions of the compounds being tested. The content of the 10% solution was based on the metal oxide AgNO_3 . After treatment, the specimens were dried at 40°C for three days, re-weighed, and then re-treated for two weeks at 27°C and 70% RH.

2.3 Chemical leaching

Chemical leaching followed the AWWA Standard Method E11-06 (AWWA, 2007b). After preparation, three samples were placed in a 500 mL bottle, immersed in 100 mL of deionized (DI) water, and subjected to a vacuum to saturate the samples with the leaching solution. The bottles were agitated mildly for 15 days. Leachates were collected after 7 hours, then at intervals of 1, 3, 5, 7, 9, 11, 13, and 15 days.

2.4 Decay test

Samples measuring 20×20×20 mm were equilibrated to 6% moisture content and weighed. The samples were then subjected to vacuum treatment with aqueous solutions containing 10%, 15%, and 20% of the compounds being tested. Three samples from each treatment group were weighed, dried overnight at 25°C, conditioned for two weeks, and then reweighed. The mass loss percentage was then calculated.

2.5 Contact angle test

Samples measuring 20×20×20 mm were equilibrated to 6% moisture content and weighed. The samples were then subjected to vacuum treatment with aqueous solutions containing 10%, 15%, and 20% of the compounds being tested. Three samples from each treatment group were weighed, dried overnight at 25°C, conditioned for two weeks, and then reweighed. The mass loss percentage was then calculated.

2.6 Surface modification of silver nanoparticles

To evaluate the moisture resistance and water absorption of the surface coatings after thermal cycling, a water drop contact angle test was conducted in accordance with ASTM D 5946 standard. The contact angle was measured 5 seconds after placing a droplet on the sample surface. This test was performed both before and after the thermal cycling process.

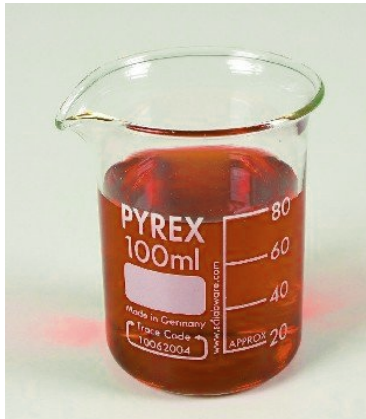


Fig. 1 Image of modified silver nanoparticle solution.

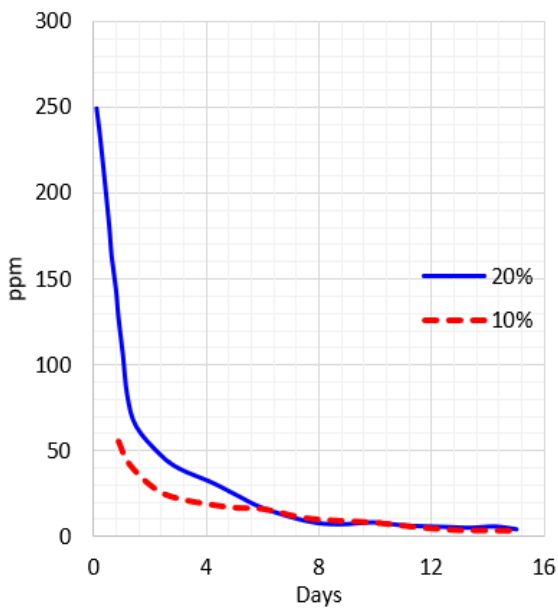


Fig. 2 Leaching rate of 10 and 20% silver nanoparticles from walnut trees treated under vacuum

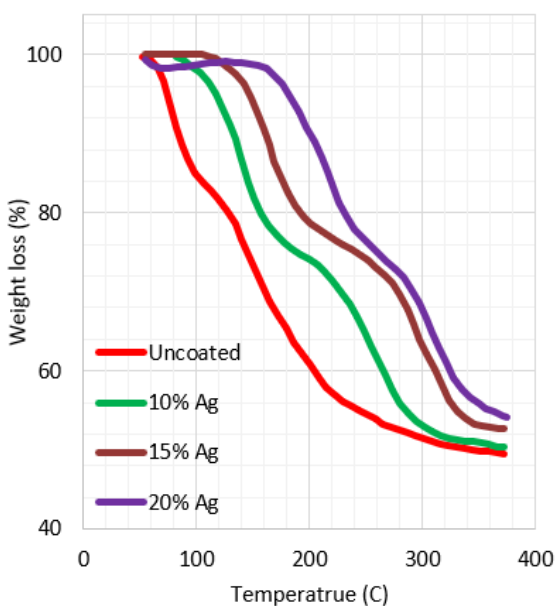


Fig. 3 TGA test results for coated samples with silver nanoparticles

3. Results and discussion

Various analytical techniques were employed to investigate the structural and compositional properties of AgNO_3 nanoparticles. The characteristics of these nanoparticles were carefully examined using X-ray diffraction (XRD), scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDS), Fourier-transform infrared spectroscopy (FTIR), and transmission electron microscopy (TEM). These analytical methods provided valuable insights into the size, morphology, chemical composition, crystal structure, and other key features of the silver nitrate nanoparticles, collectively improving our understanding of the behavior and properties of these nanomaterials.

3.1 Chemical preservation

Significant variations in chemical preservation were noted based on the size and arrangement of the samples. For example, thin samples ($20 \times 20 \times 5$ mm) demonstrated a 40% greater retention of nanosilver compared to cubic decay samples ($20 \times 20 \times 20$ mm). This discrepancy highlights how the physical dimensions and arrangement of the wood specimens can influence the retention and effectiveness of the nanosilver treatment, underscoring the importance of considering these factors in the design of wood preservation methods.

3.2 Leaching results

Fig. 2 presents the leaching rates for all test solutions across 9 times intervals for each treatment group. The results show that the silver content in the leachates from the nanosilver-treated wood was barely detectable. However, the leaching rate was notably rapid on the second day of testing. This swift leaching suggests that while nanosilver-treated wood initially releases some silver ions, the leaching rate slows down considerably after the initial exposure. Resistance to leaching is an advantageous and unexpected feature of nanosilver-treated wood, indicating that the nanoparticles effectively adhere to the wood's surface, providing long-term protection against environmental degradation. This characteristic is crucial for improving the durability of wooden instruments and materials exposed to varying environmental conditions.

3.3 Thermogravimetric Analysis (TGA) Test

The Thermogravimetric Analysis (TGA) test results, shown in Fig. 3, reveal that the mass loss in the untreated wood sample was significantly higher than in the samples coated with silver nanoparticles. The inclusion of silver nanoparticles led to improved thermal stability, thereby enhancing the durability of the nanoparticle coatings. Specifically, the mass reduction in the uncoated sample began at temperatures between 50°C and 75°C , whereas in the three coated samples, this process began at temperatures exceeding 150°C . This indicates that the silver nanoparticle coatings significantly delayed the onset of thermal degradation compared to the untreated wood. However, the

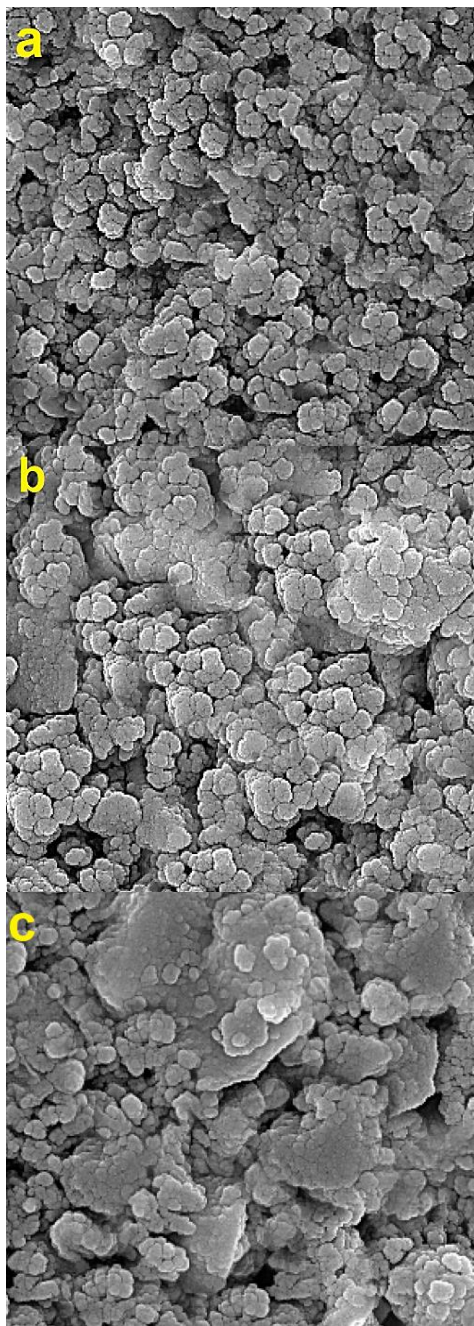


Fig. 4 SEM images of a) 20%, b) 15%, C) 10% of AgNO_3 sample

silver nanoparticle coatings displayed a gradual onset of mass reduction and thermal degradation, with an accelerated mass loss occurring only after the temperature surpassed 300°C . This gradual degradation suggests that the coatings were effective in providing enhanced thermal stability up to certain temperatures. Despite these improvements, research also indicated that the silver nanoparticle-treated samples still exhibited relatively poor resistance to spontaneous combustion, highlighting a limitation in the fire-resistant properties of these coatings. Nonetheless, the incorporation of silver nanoparticles did provide a noticeable enhancement in the thermal stability of the wood samples.

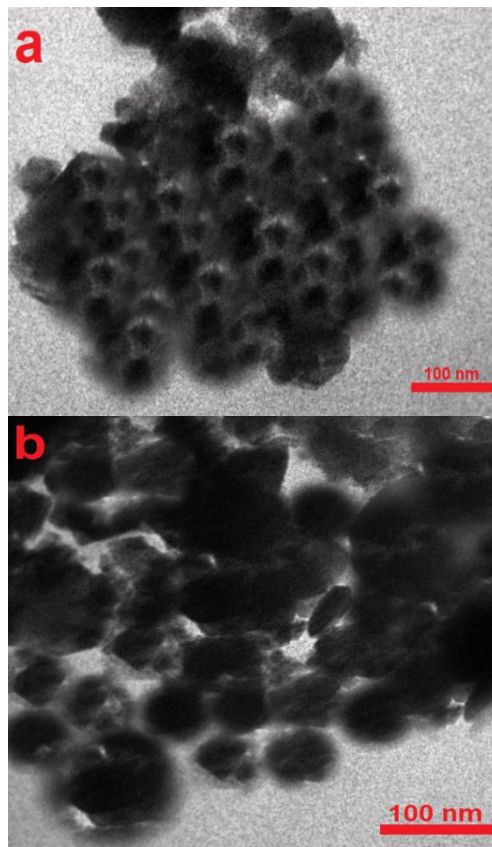


Fig. 5 TEM images of a) unmodified b) and modified AgNO_3 nanoparticles

3.4 Measurement of AgNO_3 nanoparticles with scanning electron microscope (SEM)

Fig. 4 displays the scanning electron microscopy (SEM) images of modified AgNO_3 nanoparticles at concentrations of a) 20%, b) 15%, and c) 10%. The images reveal that the AgNO_3 nanoparticles maintain a uniform and spherical morphology, with an average diameter ranging between 40–50 nm. At the 10% and 15% concentrations, the nanoparticles show uneven distribution and experience greater degradation under damp conditions, suggesting a less stable dispersion. However, at the 20% concentration, the nanoparticles exhibit a more consistent and uniform distribution, which indicates improved stability and suggests that higher concentrations of AgNO_3 nanoparticles provide better resistance to environmental factors, such as moisture, thus enhancing their effectiveness in preserving the wood's integrity. This improved dispersion is likely to contribute to the longevity and durability of wood treated with silver nanoparticles.

3.5 TEM analysis of AgNO_3 nanoparticles

The modification of AgNO_3 with KH 550 resulted in an increase in the size of the nanoparticles. The addition of KH 550 introduces a silica coating layer around the nanoparticles, which can affect their activity and behavior. This change in nanoparticle size was observed through Transmission Electron Microscopy (TEM), as shown in Fig.

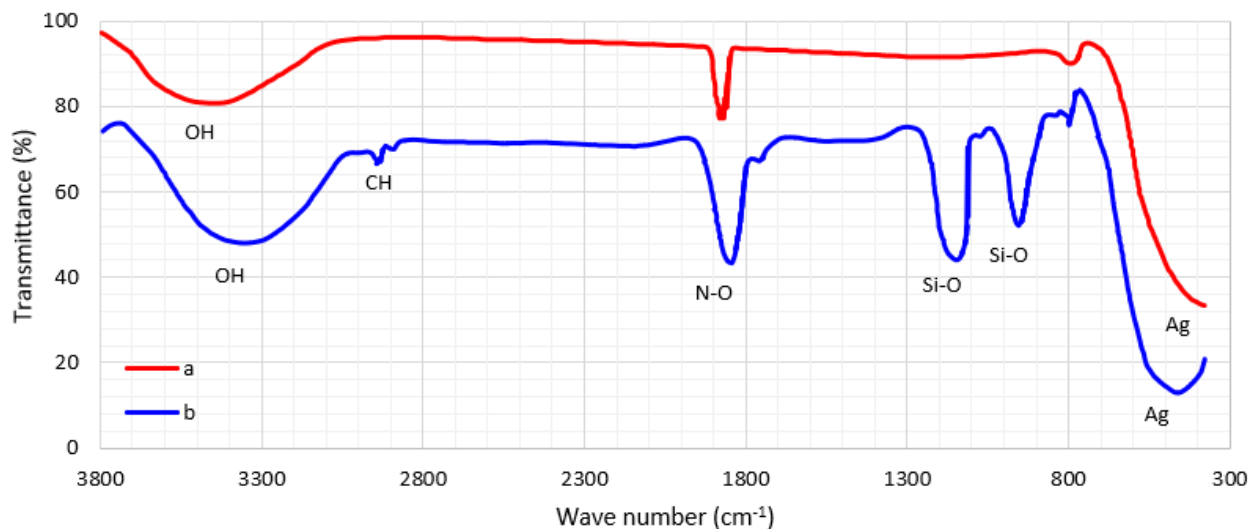


Fig. 6. FT-IR spectra of a) pure AgNO_3 nanoparticles and b) AgNO_3 modified with KH550.

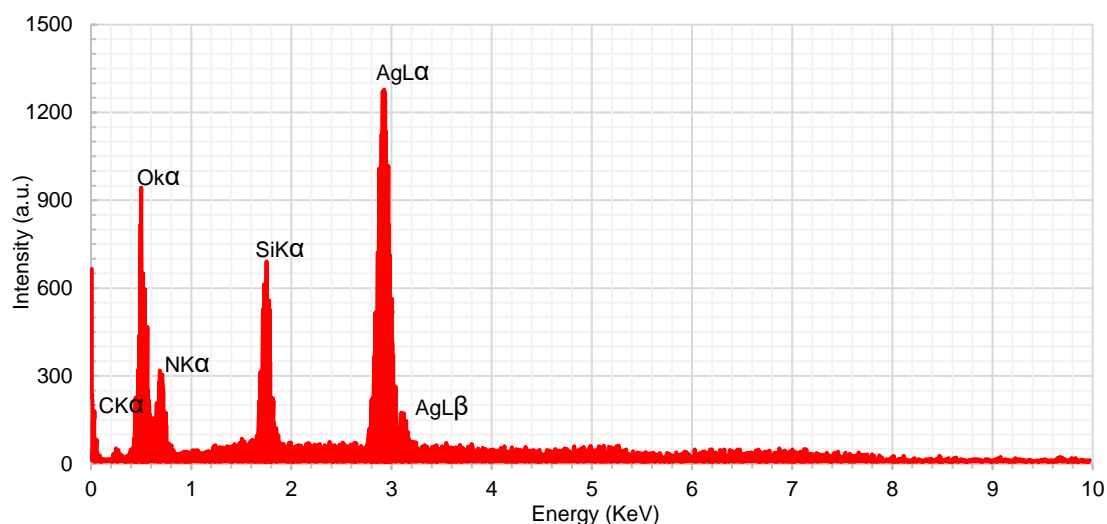


Fig. 7 EDX spectrum of AgNO_3 nanoparticles

5. The dimensions of the unmodified AgNO_3 nanoparticles (a) and the modified AgNO_3 nanoparticles (b) were determined using image analysis, revealing sizes of 100 nm and 200 nm, respectively. Both sets of nanoparticles exhibited a symmetrical size distribution. Additionally, in both cases, a tendency for nanoparticle aggregation was observed, which is a common phenomenon in nanoparticle systems, particularly when they undergo modifications or interactions with other substances. The aggregation of nanoparticles could potentially influence their performance, stability, and effectiveness in applications such as wood treatment.

3.6 FT-IR spectrum of AgNO_3 nanoparticles

To confirm the structure of KH550-modified AgNO_3 nanoparticles, FT-IR spectroscopy was conducted, and the spectra were compared with that of pure AgNO_3 . The O-H stretching band appeared at 3432 cm^{-1} , and the N-H

stretching band was observed at 3430 cm^{-1} . The peak at 2950 cm^{-1} corresponds to the aliphatic C-H stretching vibration. The absorption band at 1080 cm^{-1} is attributed to Si-O, indicating the incorporation of KH550. Additionally, the absorption band at 870 cm^{-1} corresponds to the Si-O bending vibration. Fig. 6 shows the FT-IR spectra of pure AgNO_3 nanoparticles (a) and AgNO_3 treated with KH550 (b).

3.7 EDX spectrum of AgNO_3 nanoparticles

Energy dispersive X-ray analysis (EDX) analysis was conducted to identify the elements present within the structure of the synthesized AgNO_3 nanoparticles. The EDX spectrum of the AgNO_3 nanoparticles is shown in Fig. 7. This spectrum confirms the presence of C, O, N, Si, and Ag elements in the catalyst structure, which indicates the successful synthesis of AgNO_3 nanoparticles and the modification of their surface.

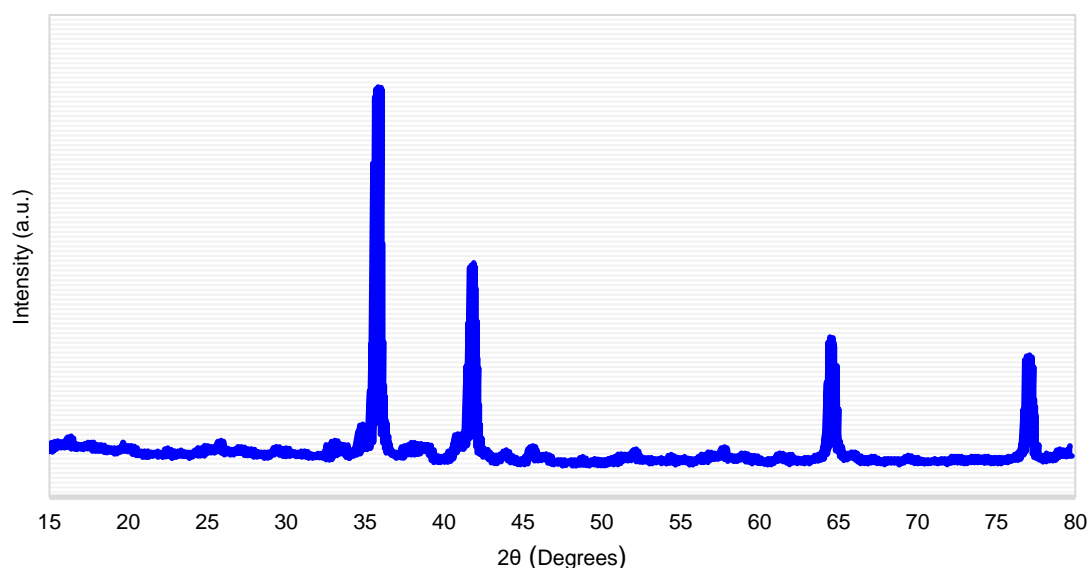


Fig. 8 XRD spectrum of AgNO₃ nanoparticles

3.8 XRD pattern of AgNO₃ nanoparticles

The X-ray diffraction (XRD) technique was used to determine the crystal structure of the synthesized AgNO₃ nanoparticles. Fig. 8 shows the XRD spectrum of the AgNO₃ nanoparticles. The spectrum reveals peaks at 36.24°, 42.61°, 65.54°, and 78.70° (2θ), which correspond precisely to the typical diffraction patterns, thereby confirming the crystallinity and structure of the AgNO₃ nanoparticles.

4. Conclusions

The integration of silver nanoparticles is an exciting and eco-friendly innovation that offers exceptional protection for wood against the harmful effects of moisture and decay caused by both environmental and biological factors. This cutting-edge technology utilizes the remarkable properties of silver nanoparticles to significantly enhance the lifespan of wood, which means fewer repairs and replacements are necessary. Moreover, it plays a crucial role in reducing unwanted sounds and disturbances in musical settings.

Scanning electron microscopy (SEM) images reveal a striking improvement in moisture resistance thanks to the protective coating created with silver nanoparticles. This nanoscale layer serves as a robust barrier, effectively blocking water and moisture from penetrating the wood's structure. Research indicates that increasing the concentration of silver nanoparticles in the coating further boosts its protective qualities, as higher concentrations yield a denser, more efficient barrier.

In addition, findings from thermogravimetric analysis (TGA) demonstrate that incorporating silver nanoparticles into wood coatings not only enhances fire resistance but also improves the coating's ability to withstand heat. This dual benefit not only increases the safety of wood but also lessens the risk of fire spreading.

By embracing this innovative approach, we can help conserve our invaluable natural resources, reduce the demand for wood, and decrease the environmental pollution associated with wood production and consumption. This is more than just a technological breakthrough; it's a dedicated step towards a greener and safer future for all of us. Let's champion sustainable, eco-friendly practices together and pave the way for a brighter tomorrow!

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