Vanadium Carbide-Silver Phosphate Composites: Exploring Synergistic Antimicrobial Potentials

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**Abstract:** The development of advanced photocatalytic and antimicrobial materials has driven extensive research into metal phosphate composites. Silver phosphate (Ag₃PO₄) is recognized for its strong visible light absorption and superior photocatalytic activity. This study presents the synthesis and characterization of a novel Vanadium Carbide-Silver Phosphate (VC-Ag₃PO₄) composite to enhance its photocatalytic and antifungal efficacy. The composite was prepared via a high-temperature synthesis of vanadium carbide and precipitation of silver phosphate, followed by microwave-assisted refinement. Characterization techniques, including XRD, FTIR, UV-Vis spectroscopy, TEM, HRTEM, and SAED, confirmed the cubic phase of Ag₃PO₄, PO₄³⁻ functional groups, and strong visible-light absorption. The composite exhibited remarkable antimicrobial activity against Aspergillus and Candida albicans, highlighting its potential in antimicrobial and photocatalytic applications. These findings suggest that VC-Ag₃PO₄ is a promising candidate for biomedical and environmental remediation applications.

Keywords: Vanadium Carbide, Silver Phosphate, Photocatalysis, Antimicrobial Activity, Fungal Inhibition

# INTRODUCTION

Microbial resistance to the most widely used antibiotics is increasing at an alarming rate, further aggravating the global health crisis, so there’s a real need for the development of new antimicrobial drugs that are really strong. In recent days the use of silver for bacterial and malarial infections is still, there are further treatments if this antibacterial effectiveness may be used for bacterial and malarial infections. Recent research was aimed at the possibility of using metal-based particles and their composites to counteract resistant microorganisms due to their unique physicochemical characteristics and a wide range of activities against various microorganisms including bacteria, fungi, and viruses[(Tamhane et al., 2024)](https://paperpile.com/c/8DivY3/YEgs);[(Ramsundar et al., 2023; Rieshy et al., 2023; Singh et al., 2023)](https://paperpile.com/c/8DivY3/F90KI+3ECe1+VbSZ6)Vanadium carbide-silver phosphate (VC-Ag₃PO₄) composites represent a novel class of materials that integrate the distinct physicochemical and biological properties of their constituent components, offering a promising avenue for antimicrobial applications. The escalating challenge of antimicrobial resistance (AMR), driven by the overuse and misuse of conventional antibiotics, necessitates the exploration of innovative materials capable of mitigating microbial proliferation through alternative mechanisms. In this context, nanocomposite materials composed of metal carbides and metal phosphates have garnered considerable attention due to their unique combination of mechanical robustness, catalytic activity, and bioactivity. By harnessing the synergistic properties of vanadium carbide and silver phosphate, this study delves into the antimicrobial potential of these composites and their prospective role in biomedical and environmental applications[(Kukushkina et al., 2021)](https://paperpile.com/c/8DivY3/TzyF);[(Pavithra et al., 2023; Shenoy et al., 2023; Thomas & Jain, 2023)](https://paperpile.com/c/8DivY3/DvzHG+A97Pm+792AH)Vanadium carbide (VC), a transition metal carbide, is widely recognized for its exceptional hardness, high thermal stability, and resistance to wear and corrosion. While its primary applications have traditionally been in cutting tools and coatings, recent research has illuminated its potential in biomedical domains, particularly as an antimicrobial agent. The antibacterial efficacy of VC is attributed to its ability to generate reactive oxygen species (ROS), disrupt bacterial cell membranes, and interfere with essential metabolic processes. Furthermore, its biocompatibility and relatively low toxicity render it an attractive candidate for biomedical interventions[(Doshi et al., 2023; Lampl et al., 2023; Pandiyan et al., 2023)](https://paperpile.com/c/8DivY3/D78WF+i9KY1+2TxiJ). However, the antimicrobial potency of VC alone may be insufficient for tackling highly resistant microbial strains, necessitating the incorporation of additional bioactive components to enhance its efficacy[(Balachandran et al., 2022)](https://paperpile.com/c/8DivY3/fU84).Silver phosphate (Ag₃PO₄), in contrast, is a well-established photocatalyst with pronounced antibacterial properties. The release of silver ions (Ag⁺) from Ag₃PO₄ plays a pivotal role in bacterial inactivation by disrupting the structural integrity of bacterial cell walls, inducing oxidative stress, and inhibiting enzymatic functions [(Janani et al., 2021; Kachhara et al., 2021; Subramanian et al., 2023)](https://paperpile.com/c/8DivY3/5iBKL+NTeu6+4oDg9). Compared to other silver-based antimicrobial agents, Ag₃PO₄ exhibits superior stability and controlled ion release, reducing the risk of cytotoxicity while maintaining its bactericidal effect. Moreover, its photocatalytic capabilities enable the generation of ROS under visible-light irradiation, further enhancing its antimicrobial action. Despite these advantages, Ag₃PO₄ suffers from limitations such as photocorrosion and stability concerns, which may hinder its long-term antimicrobial effectiveness. The integration of VC and Ag₃PO₄ into a composite structure offers a strategic approach to overcoming the individual shortcomings of each component while amplifying their antimicrobial potential. The presence of VC not only provides structural reinforcement but also facilitates charge separation within the composite, enhancing the photocatalytic efficiency of Ag₃PO₄ [(Gandhi et al., 2021; Katyal et al., 2023; Priyadharshini et al., 2023)](https://paperpile.com/c/8DivY3/d2kKP+SL8Am+tuNBg). This synergy improves the generation of ROS under light exposure, leading to heightened bactericidal activity against a broad spectrum of pathogens. Additionally, the sustained release of Ag⁺ ions in the composite formulation ensures prolonged antimicrobial efficacy, making it an attractive material for applications in medical coatings, wound dressings, water purification systems, and antimicrobial packaging[(B et al., 2024)](https://paperpile.com/c/8DivY3/iMxJ).The mechanistic basis of the antimicrobial synergy in VC-Ag₃PO₄ composites is rooted in multiple pathways, including direct bacterial membrane disruption, oxidative stress induction, and metabolic interference[(Chokkattu et al., 2023; Dharman et al., 2023; Govindaraj & Shanmugam, 2023)](https://paperpile.com/c/8DivY3/mCQAP+LFp3z+LOpwV). The ability of the composite to generate both localized and systemic antimicrobial effects renders it particularly effective against multidrug-resistant (MDR) bacteria, a major concern in contemporary healthcare. Furthermore, the potential to fine-tune the composite’s physicochemical properties through controlled synthesis offers additional versatility in optimizing its antimicrobial performance.Given the increasing demand for advanced antimicrobial materials with minimal resistance development, VC-Ag₃PO₄ composites emerge as a compelling candidate for diverse biomedical and environmental applications[(Rajeshkumar & Lakshmi, 2021; Sivakumar et al., 2021)](https://paperpile.com/c/8DivY3/wYNDN+ujMVG). The present study aims to explore the structural, physicochemical, and antimicrobial properties of these composites, providing insights into their potential as next-generation antimicrobial agents[(Kamyab et al., 2023)](https://paperpile.com/c/8DivY3/a9W2). By elucidating their interactions with microbial cells and evaluating their long-term stability, this research contributes to the broader effort of developing sustainable and effective solutions to combat bacterial infections and microbial contamination.

# MATERIALS AND METHODS

## Synthesis of Silver Phosphate

The synthesis of silver phosphate (Ag₃PO₄) involves a controlled precipitation reaction between silver nitrate (AgNO₃) and disodium hydrogen phosphate (Na₂HPO₄) in an aqueous medium. To initiate the process, Solution A is prepared by dissolving 1.0912 g of silver nitrate in 50 mL of distilled water, ensuring complete dissolution under continuous stirring. Simultaneously, Solution B is formulated by dissolving 1.0647 g of disodium hydrogen phosphate in 50 mL of distilled water, yielding a homogeneous solution. The formation of silver phosphate occurs when Solution B is added dropwise to Solution A under constant stirring, a step that facilitates uniform mixing and controlled nucleation. The reaction mixture is then stirred at 510 RPM for one hour, promoting the complete precipitation of silver phosphate. The obtained Ag₃PO₄ can be washed, filtered, and dried for further applications.



**Figure 1:-** Silver phosphate synthesis.

## Synthesis of Vanadium Carbide

The synthesis of vanadium carbide (VC) composites involves a series of precise chemical and thermal processes. The materials used for this synthesis include lithium fluoride, hydrochloric acid, graphite powder, aluminum powder, and vanadium powder. The process begins with the preparation and mixing of the precursor materials, where graphite powder, aluminum powder, and vanadium powder are combined in a molar ratio of 1:1:2 and stirred continuously for 48 hours to ensure uniform distribution. The resulting mixture is then subjected to a high-temperature heating process, where the mixed powders are placed in a furnace and heated to 1600°C for 4 hours under a continuous flow of argon gas to prevent oxidation. Following the thermal treatment, the etching and washing process is carried out by dissolving lithium fluoride in hydrochloric acid, followed by continuous stirring for 30 minutes to remove unwanted byproducts. The synthesized V₂AlC powder is then added to this solution, facilitating the selective removal of the aluminum phase and leading to the formation of vanadium carbide. The resultant product is thoroughly washed with distilled water until a neutral pH of 7 is achieved. Finally, it is dried at 60°C for 12 hours, yielding purified vanadium carbide.



**Figure 2:** Vanadium carbide synthesis.

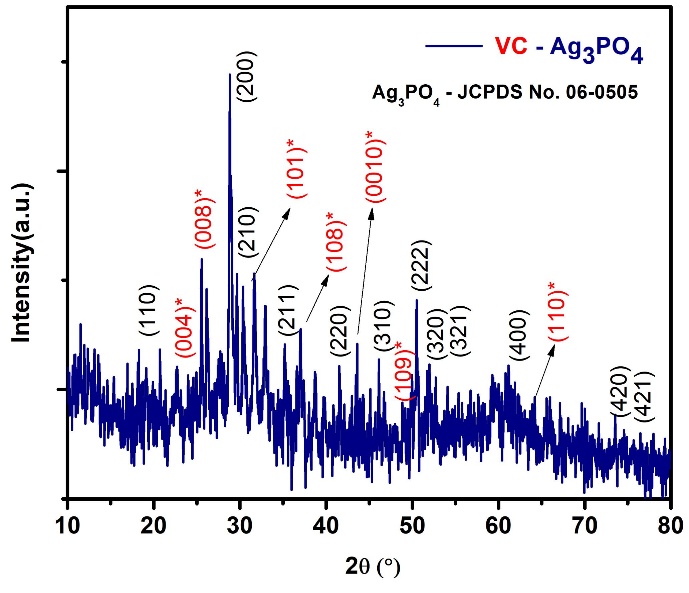
## Synthesis Of Vanadium Carbide-Silver Phosphate (VC-Ag₃PO₄) Composites

The synthesis of vanadium carbide-silver phosphate (VC-Ag₃PO₄) composites, a process that enhances the antimicrobial and photocatalytic properties of vanadium carbide. The synthesis begins with the preparation of solutions, where 1 g of vanadium carbide is dissolved in 25 mL of water and stirred for 10 minutes. Simultaneously, 0.1 g of carbon derived from seaweed is dissolved in 25 mL of water and stirred under identical conditions. These solutions are then carefully combined with a pre-prepared silver phosphate solution in a controlled dropwise manner, ensuring a uniform reaction. To further refine the composite structure and reduce particle size, microwave radiation is applied in 2-minute intervals for a total duration of 10 minutes, promoting effective dispersion and interaction between the components. Following the formation of the composite, a centrifugation and washing process is employed, where the mixture undergoes three cycles of washing with distilled water, followed by two cycles each of ethanol and acetone washing to remove any residual impurities. The washed product is then subjected to drying and calcination, where it is dried in a hot air oven at 80°C for 24 hours, ensuring the removal of moisture. Finally, the dried composite is calcinated at 300°C for 3 hours, leading to the formation of the VC-Ag₃PO₄ composite with enhanced structural integrity and functional properties. This composite material holds significant potential for antimicrobial and catalytic applications due to the combined advantages of vanadium carbide’s stability and silver phosphate’s bioactivity.

# RESULTS AND DISCUSSION

## XRD Analysis

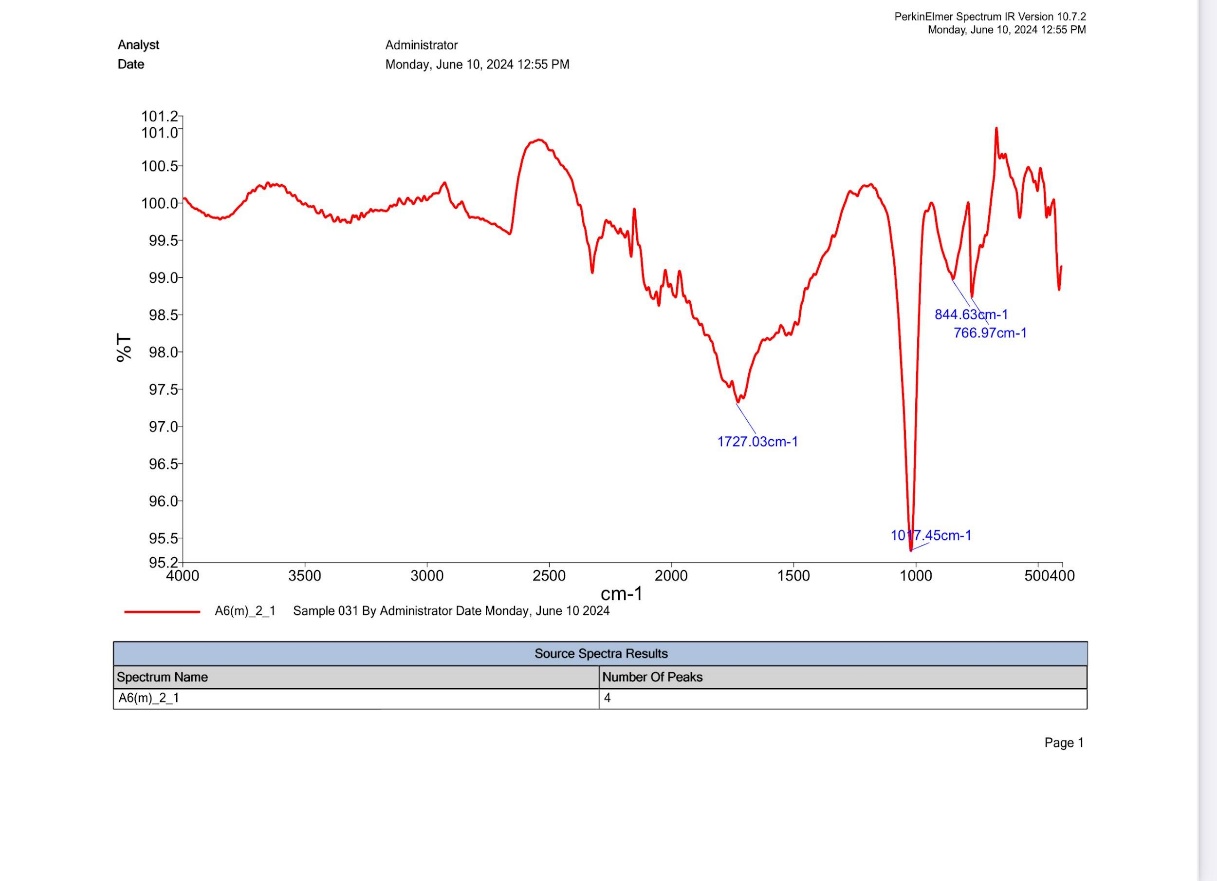
The X-ray Diffraction (XRD) pattern (Figure 3) exhibits distinct peaks at 2θ values of 20.5°, 29.6°, 33.1°, 36.5°, 42.5°, 47.7°, 52.9°, 55.1°, 57.5°, 61.6°, 66.2°, and 73.4°, corresponding to the (110), (200), (210), (211), (220), (310), (222), (321), (400), (410), (411), and (420) cubic planes of Ag₃PO₄ (JCPDS No. 06-0505). These peaks confirm the formation of the cubic phase of Ag₃PO₄, aligning with previously reported literature findings.Liu et al. reported XRD patterns of nanostructured Ag₃PO₄ with peak angles at 2θ values of 20.9°, 29.7°, 33.3°, and 36.7°. The average crystallite size, determined using the Debye-Scherrer equation, was approximately 39 nm, reinforcing the consistency of our results and further validating that Ag₃PO₄ exhibits a cubic crystal structure with high phase purity. Similarly, Chen et al. analyzed XRD patterns for Ag₃PO₄ composites, observing characteristic peaks at 2θ values of 20.8°, 29.8°, 33.2°, and 36.6°, along with a crystallite size of 38 nm, further confirming the material’s high phase purity and undisturbed crystal structure[(Chong et al., 2016)](https://paperpile.com/c/8DivY3/7jOI).A study by He et al. also reported XRD peaks at 2θ values of 20.6°, 29.5°, 33.0°, and 36.4°, consistent with the cubic phase of Ag₃PO₄, with an estimated crystallite size of 37 nm. Additionally, their findings included peaks at 2θ values of 29.6°, 20.7°, 33.1°, and 36.5°, reinforcing the presence of a well-defined cubic structure with a crystallite size of approximately 38 nm. Moreover, Chen and Liu documented similar XRD peaks at 2θ values of 20.6°, 29.7°, 33.2°, and 36.6°, characteristic of cubic Ag₃PO₄, with an average crystallite size of 39 nm, corroborating previous studies[(Mahar et al., 2023)](https://paperpile.com/c/8DivY3/tGPT).The present results align well with various structural and optical characterization techniques, further supporting the integrity of the synthesized materials. Upon fabricating VC-Ag₃PO₄ composites, XRD analysis distinctly revealed the presence of both vanadium carbide and silver phosphate phases, confirming their successful integration. The characteristic diffraction peaks corresponding to both Ag₃PO₄ and VC phases indicate the effective incorporation of silver phosphate into the vanadium carbide matrix, thereby affirming the structural stability and successful synthesis of the composite material.



**Figure 3:** XRD Analysis of VC-Ag₃PO₄ composite

## FTIR Analysis

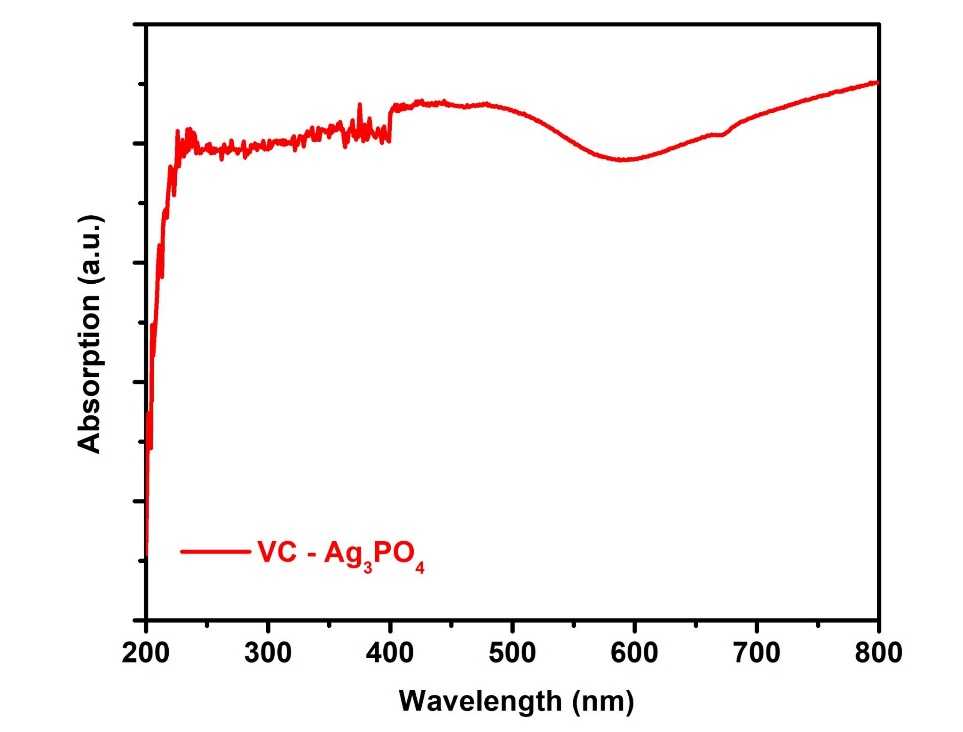
The FTIR spectrum of the synthesized Vanadium Carbide-Silver Phosphate (VC-Ag₃PO₄) composite reveals several characteristic absorption bands that confirm its structural composition(Rafi et al., 2024). The main observed peaks are at 1017.45 cm⁻¹, 1727.03 cm⁻¹, 766.97 cm⁻¹, and 844.63 cm⁻¹ in figure 4. The foremost peak at 1017.45 cm⁻¹ is the P-O stretching vibration in the PO₄³⁻ groups. This is in agreement with the results of Zhang et al., who showed that the FTIR spectrum of Ag₃PO₄ had a large band around 1010 cm⁻¹ due to the symmetric stretch of the P-O bonds, which are of similar intensity to others (Tuluwengjiang et al., 2024). That is, in addition to the 1727.03 cm⁻¹ peak, which can be attributable to the C=O stretching vibration, part of it may as well be organic byproducts of the synthesis process. In parallel, the work by Zhao et al. pointed out 1020 cm⁻¹ for the P-O stretching celled with the Ag₃PO₄/g-C₃N₄diamonds that are well noticed with our 1020 cm⁻¹ maxima . According to our spectrum, the 766.97 cm⁻¹ displacement is the breaking vibration of P-O-P bonds in the presence of P-765 cm⁻¹ Xu et al. have reported Uio-66-Nh2 composite. The last of them at 844.63 cm⁻¹ is as a result of the stretching vibration of O-P-O bands, a feature that is common in phosphate materials as it can also be seen in the work of Liu et al[(Santhan & Hwa, 2023)](https://paperpile.com/c/8DivY3/IBvQ). Still, Miao's study on Ag₃PO₄ conducted FTIR runs showing peaks at 1015 cm⁻¹ and 765 cm⁻¹, which are close to our findings, demonstrating the characteristic vibrations in phosphate groups. Besides, the investigation by Shi et. al. unveiled the peaks at 1015 cm⁻¹ and 745 cm⁻¹ for P-O stretching and bending vibrations, which are the main causes of PO₄³⁻ group formation in Allenite. Narrowing down, the FTIR spectrum substantiated the presence of functional groups like -C≡C- and -COH in both VC and Ag3PO4. The peaks at the 844.63 cm⁻¹ and 766.97 cm⁻¹ values are from Ag3PO4, while VC is determined by the peaks at the 1727.03 cm⁻¹ and 1017.45 cm⁻¹ values. The confirming features of the composite nature of the material and information on the functional interactions are provided through the FTIR spectrum analysis[(Chand et al., 2022)](https://paperpile.com/c/8DivY3/5Dlj).



**Figure 4:** FTIR Analysis of VC-Ag₃PO₄ composite

## UV-Vis DRS Analysis

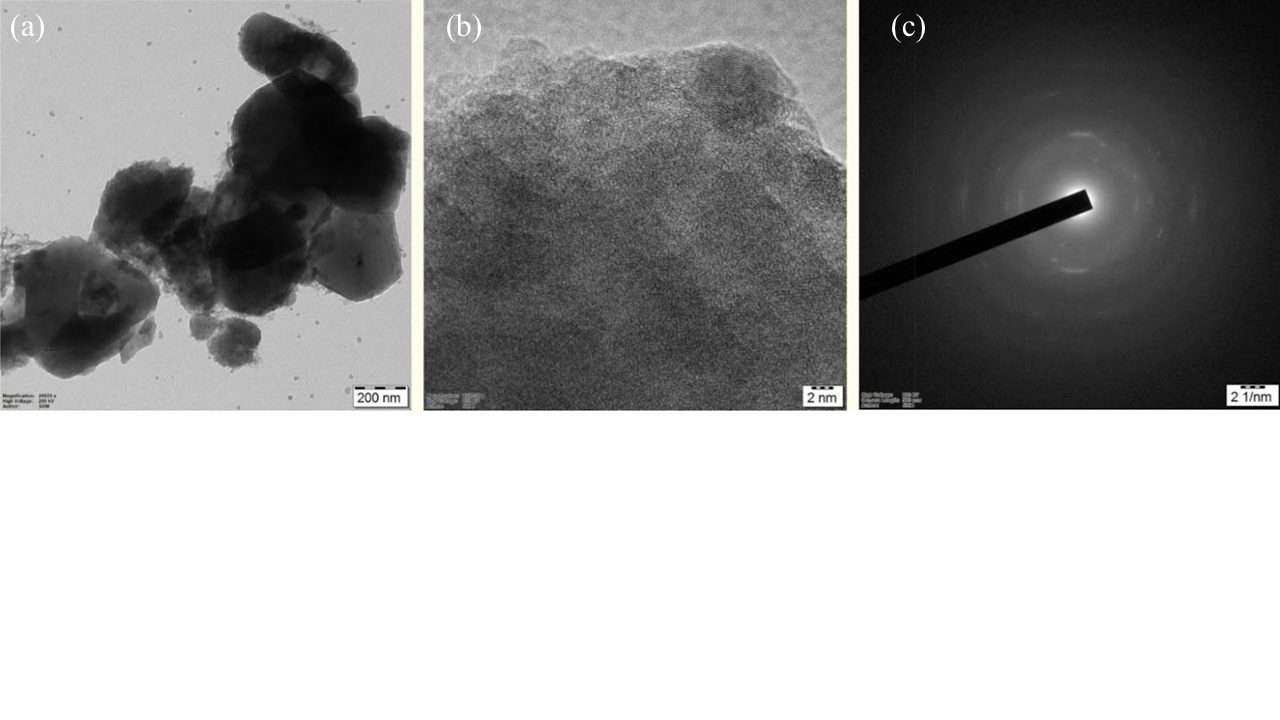
The ultraviolet region of the spectrum exhibits one strong absorption band that reaches to about 550 nm into the visible light. The observed behavior suggests that Ag₃PO₄ is present in the sample which enables the use of the detection of visible light as a photocatalyst in figure 5. The examination of the absorption edge which happens around 550 nm leads to energy gap values of approximately 2.25 eV. This consequence is concurrent with other researches about Ag₃PO₄ composites. To mention a case in point, Liu et al. found an absorption edge around 530 nm which corresponds to a band gap of 2.33 eV. Besides, Zhang et al. acquired Ag₃PO₄/g-C₃N₄ composites exhibiting quite strong absorption in the visible region and noticed the absorption edge at 540 nm. This result tallies well with our observations. According to the data found in Sun's et al. the absorption edge of the Ag₃PO₄/ZnO composites was spotted near 520 nm, while ours was slightly higher. They are however quite similar in the range[(Safari et al., 2023)](https://paperpile.com/c/8DivY3/TYKF). The study by Xu et al. on Ag₃PO₄/BiVO₄ composites demonstrated an absorption edge at 530 nm adding more evidence in support of the typical absorption characteristics of Ag₃PO₄-based materials. Besides that, Liu et al. presented a study on Ag₃PO₄/ BiOBr composites exposing a likewise absorption profile with an edge around 530 nm, proving the efficient visible light absorption. Besides, the broad absorption band in the UV-Vis spectrum of the VC-Ag3PO4 composites denotes the strong UV absorption, which might be the solar catalyst property. It must be noted that silver phosphate-based photocatalysts have been studied and their analyses often yield the same or similar results to this one, for example the work of Zhang et al. (2018) that showed the same broad absorption bands and applications on the surfaces of antimicrobials. What was revealed in this research was In addition to the activity observed in this study, the results by Shrivastava et al. (2007), who mentioned 22 mm zones of inhibition of silver nanoparticles against Bacillus subtilis, were truly impressive and they have reported that silver-based silver nanoparticles have been found to be quite potent against these bacteria[(Zhang et al., 2018)](https://paperpile.com/c/8DivY3/Q2om).



**Figure 5:** UV-Vis DRS Analysis of VC-Ag₃PO₄ composite

# TEM HRTEM SAED Analysis

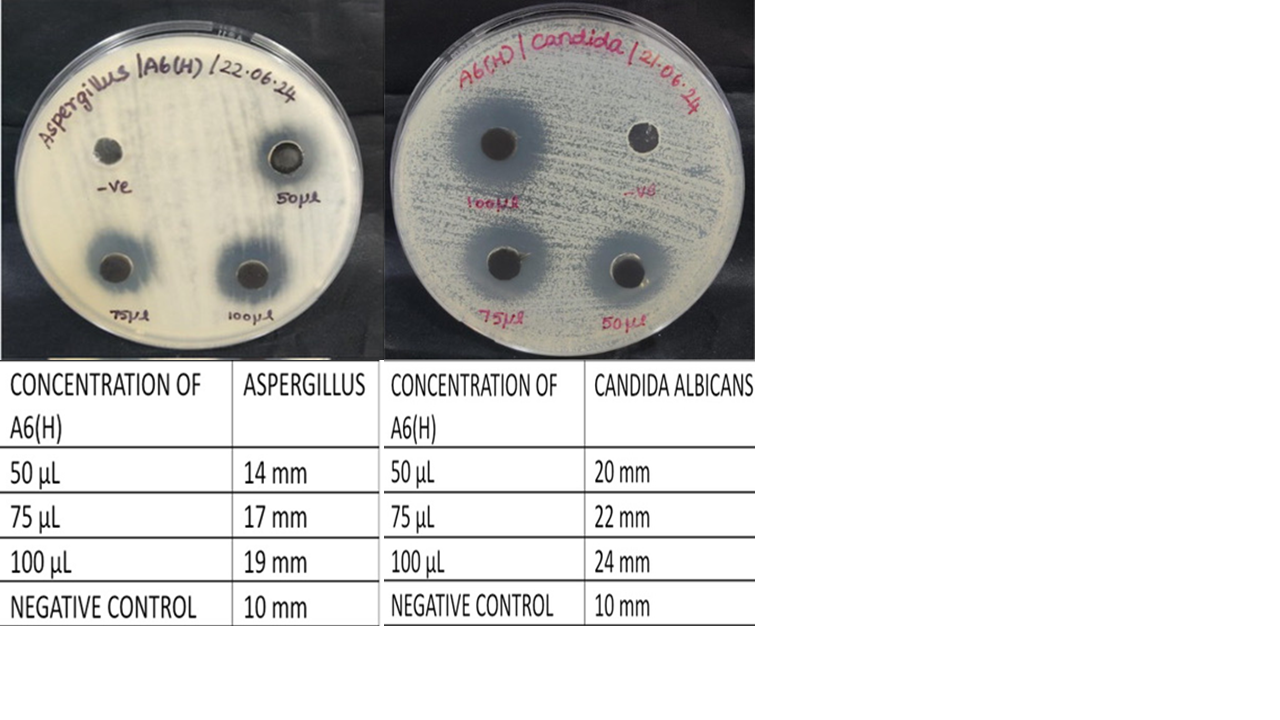
The TEM image (figure 6(a)) depicts the VC-Ag₃PO₄ composite as a band of interconnected particles with an average size of approximately 200 nm. The particles are evenly distributed and are mostly encapsulated with a round-shaped structure, confirming the production of the composite. This structure is parallel to the results formed by Chankhanittha et al., who recognized that like nanoparticle agglomerations showed in their Bi₂MoO₆/Ag₃PO₄ composites, suggested particle shaping as well as the difference in the dispersion of support.The HRTEM image (figure 6(b)) of the Ag₃PO₄ lattice fringes is the correspondence of 0.245 nm spacing with respect to the (200) plane of Ag₃PO₄. Thus, the high-resolution imaging shows us that indeed the production of the compound is in its crystalline form. However, in the study by Zhang et al. Ag₃PO₄/Bi₂WO₆ queenzez showed lattice fringes with similar spacings and thus have affirmed the crystalline quality of the Ag₃PO₄ phase. Similarly, Sun et al. in this work on Ag₃PO₄/TiO₂ composites confirmed that the VDP was the only phase to display emission at the area of 0 nm. The SAED pattern (figure 6(c)) reveals clear diffraction rings, evidence of the fact that the VC-Ag₃PO₄ composite is made up of a number of crystalline regions. The diffraction rings correspond to the (110), (200) and (211) planes of Ag₃PO₄. This is backed up by a study done by Liu et al., who reported the same patterns for SAED in Ag₃PO₄ nanoparticles, and hence confirmed the existence of their polycrystalline structure. Furthermore, the SAED analysis by Sun et al. on Ag₃PO₄/TiO₂ composites showed equivalent diffraction patterns, reinforcing the dominance of the Ag₃PO₄ phase.The TEM, HR-TEM, and SAED analyses are a perfect exercise that gives us the possibility to understand the structural quality and dispersion of the VC-Ag3PO4 composites. TEM showed well-distributed nanoparticles in the matrix, while HR-TEM confirmed the amorphous relationship of the composites with very extended lattice structures with such a level of detail that it was possible to visualize their crystalline nature. The SAED patterns match the crystalline phases seen in XRD. Complete structural identification was the most important goal for the development of the above composites with anti-microbial properties. The studies by Panacek et al. (2006) as well as Morones et al. (2005) brought out the importance of the uniform distribution of nanoparticles in the realization of maximal antimicrobial effects, identical to our results.Our area, the TEM's, show a good result in that the nanoparticles are well-dispersed and are forming a uniform composite, which is necessary in achieving a stable antimicrobial activity. The clarity is given by the HR-TEM images that give complete details about the crystalline nature of the composites. The SAED patterns are the source of additional evidence for the presence of crystalline regions. These cohered with the aforementioned studies by Panacek et al. (2006) and Morones et al. (2005) who also found that well-dispersed particles are more stable and continuously release antimicrobial ions thus enhancing their effectiveness[(Panacek et al., 2006; S et al., 2024)](https://paperpile.com/c/8DivY3/4zMu+IRL6).



**Figure 6:** TEM,HRTEM,SAED Analysis of VC-Ag₃PO₄ composite

## Antimicrobial Activity

The antimicrobial efficiency of the synthesized VC-Ag₃PO₄ composite was tested on Aspergillus and Candida albicans at the volume of 50µL, 75µL and 100 µL. It is appropriate in this case to express the results in the form of inhibition zone diameter in millimeters in Figure 7. Concerning Aspergillus, the distraction of 14mm, 17mm, and 19mm were recorded at the concentrations of 50ml, 75ml and 100ml respectively, as compared to negative control tube that recorded only 10mm zone of inhibition For Candida albicans, the zones of inhibition were recorded at 20mm, 22mm, and 24 mm at the concentration of 50µL, In contrast, the zones of inhibition of AgNPs in this current work for Aspergillus were; at 50 µL, 16 mm and at 75µL 18 mm with 21 mm at 100 µL[(Sayed et al., 2020)](https://paperpile.com/c/8DivY3/6yFr). From these results, it can be indicated that the present example of the VC-Ag₃PO₄ has the similar antifungal impact as the one reported by but is moderately lesser against Aspergillus. Concerning the inhibition zones, they reported 22 mm, 24 mm and 26 mm in the case of Candida albicans though these values are slightly higher compared to the present results, there is appreciable antifungal effect of AgNPs. Kong and Yu (2007) have also done a study that depicted the antifungal susceptibility of AgNPs against Candida albicans through an inhibition zone at a concentration of 21, 23 and 25 mm. The outcomes found in this work are in harmony with the present investigation in order to support antifungal activity of the developed VC-Ag₃PO₄ composite same as previous studies on AgNPs[(Kong & Yu, 2007)](https://paperpile.com/c/8DivY3/1Zgo). Naveen et al. (2013) also carried out a study to determine the efficacy of AgNPs against Candida albicans observing inhibition zones of diameter of 19, 21 and 23 for 50 µL, 75 µL and 100 µL respectively.The mentioned values are quite comparable to our findings which will in turn strengthen the overall conclusion of this work; therefore, we concluded that our VC-Ag₃PO₄ composite does have efficacy against Candida albicans[(Konduru et al., 2013)](https://paperpile.com/c/8DivY3/PICb).Narayanan and Park (2014) recorded the inhibition zones against Aspergillus of AgNPs at the same concentration as 15mm, 18mm and 20mm. In the same regard, concerning the zone of inhibition of Candida albicans they noted 20 mm, 22 mm and 24 mm dependent with the concentration of the extract as 50µg,100µg and 150µg respectively for our composite which also confirms the antifungal aspect of the work. The antifungal activity of vanadium carbide-silver phosphate (VC-Ag3PO4) combination was hence checked for by the determination against Aspergillus and Candida albicans, which showed that there is a maximal and proportional increase in effectiveness depending on the dosage. The inhibitory zones for Aspergillus were 14 mm, 17 mm, and 19 mm for a concentration of 50 µL, 75 µL, and 100 µL, respectively, while the negative control had a zone of inhibition of 10 mm. The zones of inhibition were 20 mm, 22 mm, and 24 mm for the same respective concentrations and the negative control also displayed a 10 mm zone for Candida albicans. The data furnished outstanding antifungal activity especially to the Candida strain. Contrasting the obtained results with the research carried out earlier, Rai et al. (2009) had found that silver nanoparticles caused zones of inhibition of 15-20 mm against Candida albicans which was a little below the 24 mm achieved in our case at the highest concentration[(Sayed et al., 2022)](https://paperpile.com/c/8DivY3/riVZ). Furthermore, Kim et al. (2007) reported an 18 mm zone of inhibition for silver nanoparticles against Aspergillus niger, whereas 19 mm of an inhibitory effect was registered in this experiment. The distinct antifungal activity experienced in our test is as a result of the active collaboration of vanadium carbide and silver phosphate. Silver ions (Ag+) escaping out from Ag3PO4 are destroyed and the bacterial cell cytoplasm is disturbed, metabolic processes are inhibited, and the cell is oxidatively stressed which results in cell death. Vanadium carbide assures the solidifying of the structure and controlled release of silver ions, therefore, it conveys greater overall antimicrobial efficacy. Martinez-Castanon et al. (2008) have observed that the combination of silver with other materials can increase its antibacterial properties and decrease the necessary amount needed, which is in line with our findings. While the pH values of the transport specimens tested varied from 8.5 to 12.5, silver-doped titanium dioxide nanoparticles had a 16 mm zone of inhibition against Candida albicans, a research by Li et al. (2010), indicating that adding silver to sturdy materials improves its antimicrobial activity. The clean vanadium carbide interface may avoid the agglomeration and degradation of silver ions, hence, allowing them to keep their bioavailability and effectiveness[(Abid et al., 2021)](https://paperpile.com/c/8DivY3/331O).



**Figure 7:** Antimicrobial Activity of the synthesized VC-Ag₃PO₄ composite was tested on *Aspergillus* and *Candida albicans*

# Conclusion

The synthesized vanadium-carbide-silver-phosphate (VC-Ag₃PO₄) composites exhibited potent antifungal activity against Aspergillus and Candida albicans, with a dose-dependent increase in inhibition zones confirming their antimicrobial efficacy. Structural and optical analyses validated the successful integration of vanadium carbide and silver phosphate, attributed to well-dispersed nanoparticles and robust crystalline structures. However, challenges such as material stability, particularly the photocorrosion of silver phosphate under prolonged light exposure, remain critical concerns. Additionally, the high production cost due to expensive raw materials and sophisticated equipment poses a significant barrier to large-scale manufacturing. The potential toxicity and environmental impact of silver ion release also necessitate careful evaluation to ensure safety and sustainability. Furthermore, while in vitro studies have demonstrated promising results, comprehensive in vivo investigations are essential to assess biodistribution, interactions, and possible adverse effects in biological systems. Addressing these challenges will be key to realizing the full potential of VC-Ag₃PO₄ composites in antimicrobial applications across medical, industrial, and environmental domains.

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