Enhanced photocatalytic and biological observations of green synthesized AC, AC/Ag and AC/Ag/TiO₂ nanocomposites

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Abstract

In this study, AC/Ag/TiO₂ nanocomposite was successfully synthesized by hydrothermal method using jasmine flower extract. The reactions of reduction, stabilization and capping was executed from the biomolecules of jasmine flower extract. The decoration of activated carbon and noble metal to the metal oxide enhanced the properties in all ways. As the modified structural, optical and morphological properties of as prepared nanocomposite was characterized using various techniques such as, X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), UV-Visible spectroscopy, Scanning electron microscope (SEM) with Energy dispersive X-ray spectroscopy (EDX), and Transmission electron microscope (TEM). The photocatalytic activities under sunlight were evaluated by the degradation of methylene blue (MB). Antibacterial activity was tested against *E-coli* and *S. aureus*. The characterization results show that AC/Ag/TiO₂ nanocomposite is crystalline, needle like morphology and highly optically active catalyst. The investigated AC/Ag/TiO₂ nanocomposite shows 96% maximum degradation efficiency at the end of 120 minutes under visible light irradiation. The degradation efficiency and antibacterial activity is readily higher than that of commercial TiO₂. The plasmonic support to the activated carbon and titanium nanoparticles creates large surface area, active sites and accelerated the free radical generation. These characteristics demonstrated that the prepared AC/Ag/TiO₂ nanocomposite material is highly suitable for the decomposition of methylene blue and waste water treatment.

1. Introduction

In the 21st century the earth is plagued by climate change, environmental pollution, and waste water management crisis. The earth is mostly occupied by water. Water is the most essential resource for all human beings. Dyes and its by-products causes major environmental pollution and the release of their chemicals can change the nature of water nature from potable to non-potable [1]. The dye waste is unscrewed to the aquatic centre, which alter the nature of the soil and their water content. It also promotes many diseases, environmental pollution and some contagious diseases. Dyes from the textile industry, food industry and paper industries play an important role in water pollution. Very low concentration of dye molecule can be very harmful to human health. There is no effective process to remove dyes, pesticides, and heavy metals from waste water. Nowadays researchers are focusing on heterogeneous nano catalyst to remove dye molecules.

Adsorption, ozonisation, membrane filtration, and flocculation are techniques used to separate heavy metals and organic dyes. Among those techniques, photocatalysis plays an important role in waste water treatment [2, 3]. The main advantage of photo catalysis is that it decomposes the dye molecules without any residues. Photo catalysis is an inexpensive, environmental-friendly and easy method [4, 5]. Silver nanoparticles have attracted intense research interest in medicine due to its excellent antibacterial performance. Silver nanoparticles are widely used in nano devices, sensors, catalyst and drug delivery [6, 7]. Plant mediated silver nanoparticles are widely used in nano medicine due to their lack of chemicals and less toxicity. Silver nanoparticles are widely used in optoelectronic devices due to its unique surface plasmon resonance. The morphological features of nanoparticles are of great interest to the catalyst because shape and size affects the properties of nanoparticles.

Activated carbon is a carbonaceous material often derived from agricultural waste. Physical and chemical methods used to synthesize activated carbon. Activated carbon has attracted significant attention in various fields due to its excellent, chemical, thermal and electrical properties [8]. Activated carbon in silver NPs to improve catalytic performance because activated carbon improves the contact area between the Ag and dye [9].

Titanium dioxide (TiO_2) is an n-type semiconductor, that is widely used as a photocatalyst due to its good thermal stability, low cost, non-toxic, and environmentally friendly properties [10]. Titanium dioxide occurs naturally in many sands and rocks. TiO_2 is a semiconductor material that can be activated by light using a band gap value of 3.2 eV. The main drawback of titanium dioxide nanoparticles is their easy agglomerated, poor absorption capacity and high electron-hole reprocessing rate. An increase in the recombination rate reduces the degradation efficiency of the nanocatalyst. TiO_2 doped with noble metal nanoparticles enhances optical and biological properties. Plasmonic nanoparticles have a strong absorption in the visible area due to its localized surface plasmon resonance [11].

The jasmine flower is used as a stabilizing agent in this current study. The bio-molecules present in the jasmine flower act as a reducing agent. We choose jasmine flower extract as it has excellent antimicrobial and medicinal properties in nature. Methylene blue is the most widely used organic dye in the printing, pesticide and chemical industries. Methylene blue causes cancer, skin itching and other diseases. Nausea, high blood pressure, haemolysis and respiratory disorders are caused by MB.

Antibacterial activity was visualized using Agar diffusion process. Antibacterial activity of silver decorated nanocomposites results excellent activity by optical activity, high surface to volume ratio. In gram negative bacteria, the bacterial cell wall membrane is 2 to 3 nm thin layer of peptidoglycan and 30 nm for gram positive respectively. The cell wall membrane is made up of proteins, phospholipids, and lipopolysaccharides. Interaction between micro-organism and nanoparticles changes in permeability and causes cell death [12].

According to Pauline Jing et al, the TiO_2/AC composite prepared using the sol-gel method reduces RhB dye by 93.2% under UV light radiation [13]. Koo et.al reports that carbon nanotubes modified silver titanium (Ag/TiO_2) nanoparticles to remove methylene blue. The environmental impact of silver is less than that of metal oxides [14]. Fangjun Wu et.al reported that graphene like bamboo charcoal modified titania nanocomposite for methylene blue removal. TiO_2/GC degrades 90 % of MB dye within 2 hours [15]. Hamrouni et.al reported that $\text{Ag}-\text{TiO}_2$ composite improves the catalytic activity with sunlight irradiation. Silver nanoparticles combined with titanium dioxide nanoparticles exhibit excellent catalytic activity compared to commercial TiO_2 [16]. Understanding the importance of the high performance heterogeneous catalyst, the effect of hazardous dyes such as MB on the environment, the authors are interested in green chemistry for synthesis of $\text{AC}/\text{Ag}/\text{TiO}_2$ nanocomposites to investigate the photo degradation of MB. $\text{AC}/\text{Ag}/\text{TiO}_2$ nanocomposites were characterized using X-ray diffraction (XRD), Fourier Transform Infrared spectroscopy (FTIR), UV-visible spectroscopy (UV-Vis), Scanning electron microscope (SEM) with Energy Dispersive X-ray dispersive spectroscopy (EDX) and Transmission Electron Microscopy (TEM). The antibacterial activity was tested against both gram-positive and gram-negative bacteria. The photo degradation of methylene blue solution was investigated using visible irradiation technique.

2. Experimental Setup

2.1 Materials and Reagents

Jasmine flower was collected from local market. Sodium hydroxide (NaOH), silver nitrate (AgNO_3), Titanium tetra isopropoxide (TTIP, 97%), hydrochloric acid (HCL), and methylene blue ($\text{C}_{16}\text{H}_{18}\text{ClN}_3\text{S}$) were purchased from Sigma Aldrich, India PVT Ltd. All the chemicals and reagents were used without any purification.

2.2 Synthesis of Ag/AC composite using jasmine flower extract

Silver nanoparticles and activated carbon were prepared by the same procedure reported by the author [17,18]. In this case, NaOH activation agent was used as the activation agent to prepare activated carbon. In a typical experiment calculated amount of activated carbon added to silver solution and stirred for 30 min. The solution mixture was

transferred to a Teflon auto clave for 5 h at 150°C for the hydrothermal process. The precipitate was centrifuged, washed with deionised water and ethanol to remove contamination and heavy biomass. The precipitate was dried in an oven at 150°C for 3 h. The final product obtained was labelled as AC/Ag composite.

2.3 Green synthesis of AC/Ag@ TiO₂ nanocomposites

In the green synthesis of AC/Ag/TiO₂ nanocomposites, jasmine flower extract based titanium dioxide nanoparticles were prepared by the same procedure as reported by the author [19]. The calculated amount of AC/Ag powder is dissolved in 20 ml of distilled water for 2 hrs to get solution. The AC/Ag composite solution was mixed with TiO₂ solution and stirred for 30 min. The mixture solution was transferred to Teflon auto clave for the hydrothermal synthesis process at 150°C for overnight. The composite solution was centrifuged, washed in distilled water and dried in oven at 150°C for 3 h. Furthermore, the prepared composite was annealed at 300°C for 3 h. the as prepared samples was named as AC/Ag/ TiO₂ nano Composite.

2.4 Materials Characterization

The structural properties of the prepared material were studied using powder X-ray diffraction with Cu-K α radiation (λ = 0.15406 nm) in the range (2 θ) of 10°C to 60°C. The vibrational modes of as prepared compounds were predicted using Perkin-Elmer FTIR spectrometer. The surface morphology was measured using scanning electron microscope (FEI NOVA NANO-SEM 450) at 5.0 kV and Transmission electron microscopy (TECNAI-G2 model operated at 200 kV). The elemental composition of as prepared composite was investigated by EDX analysis fitted to the SEM. The optical property was analysed by using SHIMADZU UV–2450 spectrophotometer in the range of 200 –800 nm.

2.5 Photocatalytic Activity Measurements

The photocatalytic activity of as prepared AC, AC/Ag, and AC/Ag/TiO₂ were tested for the degradation of methylene blue under the visible light irradiation. A 300 W xenon lamp with a 420 nm cut of filter was used as the visible light emitter. The distance between the visible light source and reaction chamber is 30 cm. The prepared photocatalyst (1 g/L) is dissolved in 20 mL of 50 ppm of methylene blue dye solution. The solution mixture was stirred for 30 min to obtain an adsorption-desorption equilibrium. Then solution mixture is exposed to UV-Visible light at regular interval of 30 min. The 2 mL of solution was centrifuged and the degradation efficiency was examined using an UV-Visible spectrophotometer. The MB dye degradation efficiency of the photocatalytic reaction was estimated using the following equation:

$$\eta (\%) = \frac{C_o - C_t}{C_o} \times 100\% \quad (1)$$

C_o represents the initial equilibrium concentration of MB dye, C is the final concentration of MB dye aqueous solution and t is the irradiation time.

2.6 Antibacterial Studies

The antibacterial activity of nanocomposites was compared using disc diffusion process. Antibacterial activity was tested against gram-positive *Bacillus subtilis* (MTCC-736) and gram negative strain *E.coli* (MTCC-443). Gentamycin is used as standard antibiotic. As prepared sample was dissolved in four different concentrations (10,20,50 and 100 μ g/ml) in sterile water and ultra-sonication to prevent accumulation. The agar medium was maintained at a pH of 7.2

to 7.4, and the agar plate was sealed overnight at 37°C. The inhibition zone is obtained after inhibition and is manually measured in mm. The antibacterial activity of the as prepared nano composite from the zone of the inhibition (ZOI) layer was compared. The formed zones were evaluated by mm scale.

3. Results And Discussions

3.1 Powder X-Ray Diffraction analysis

The crystalline phase, purity, and lattice parameters of the prepared AC, AC/Ag nanocomposite, and AC/Ag/TiO₂ nanocomposites were confirmed using the powder X-ray diffraction (XRD) technique. Fig. 1 shows the X-ray diffraction patterns of the AC, AC/Ag nanocomposite, and AC/Ag/TiO₂ nanocomposites. The characteristic peaks at 25.45° and 44.39° in Fig. 1 corresponds to the Bragg reflections of (002) and (101) planes, respectively. The broad and amorphous jasmine flower-derived activated carbon (AC) is due to pseudo-crystalline graphitic carbon formation. The obtained AC characteristics peaks exhibit the hexagonal crystal system with a point group of P63mc (186), and it well matched with the JCPDS card number 89-8487 [20]. The measured lattice parameters 'a' and 'c' were 2.459 Å and 6.708 Å. The diffraction peaks located in Fig. 1 depict the AC/Ag nanocomposite, and the diffraction angle 2θ at 38.09° and 44.41° can be indexed to (111) and (200) planes. These diffraction peaks indicate that the prepared composite contains a metallic silver phase with a cubic crystal structure. The lattice constant (a) of 4.086 Å was well-matched with JCPDS File Card No. 89-3722 with a group of Fm3m (225) [21]. It is noticed that, compared with AC, the diffraction peak at 44.41° of AC/Ag nanocomposite becomes higher, which is attributed to the overlapping of AC (101) and Ag (200) planes. From fig. 1 the diffraction peaks at 25.54°, 38.31°, 44.54°, and 54.70° are assigned to the planes of (101), (004), (200), and (105). Here all the diffraction peaks were in good agreement with the anatase phase of TiO₂ (JCPDS Card No: 21-1272) [22]. Also which exhibits the tetragonal crystalline system with the lattice constants of 4.560 Å (a) and 2.950 Å. This anatase crystalline phase is may also be responsible for the higher photocatalytic activity. The diffraction crystal plane of (004) for anatase TiO₂ and (111) for Ag was overlapped, but the crystalline structure of TiO₂ is not affected [23,24]. The presence of diffractions from carbon, Ag, and TiO₂ in Fig. 1 suggests that the prepared materials are mainly composed of graphitic, metallic silver, and anatase TiO₂ phases. The average crystallite size, dislocation density, and lattice strain of the AC, AC/Ag nanocomposite, and AC/Ag/TiO₂ nanocomposites were measured using the following Debye – Scherrer's and Williamson – Smallman relations [25] (Eq. 2-4)

$$\text{Crystallite Size (D)} = \frac{K \lambda}{\beta \cos \theta} (\text{nm}) \quad (2)$$

$$\text{Dislocation Density } (\delta) = \frac{1}{D^2} (\text{lines/m}^2) \quad (3)$$

$$\text{Lattice Strain } (\epsilon) = \frac{\beta}{\tan \theta} \quad (4)$$

Where, K is the Debye Scherrer constant, λ is the wavelength of the Cu-Kα X-ray (λ = 1.5406 Å), θ is the diffraction angle, and β is the full width at half maximum (in radian). In Table.1 predicts the average crystallite size, dislocation density, and lattice strain of the prepared photocatalysts. The average crystallite size of AC/Ag/TiO₂ nanocomposites decreases with increasing the lattice strain as well as dislocation density, which may increase the surface area of the AC/Ag/TiO₂ nanocomposites. The large surface area can facilitate more surface sites and lattice disorders, enhancing the AC/Ag/TiO₂ nanocomposites photocatalytic activity. The smaller crystalline size can also migrate the photoexcited

charge carriers to the photocatalyst surface, which may reduce the electron-hole pair recombination rate, where it has played a significant role in refining the photodegradation performance.

3.2 Fourier Transform Infra-Red Spectrum analysis

The functional group vibrational modes present in the prepared material were identified using Fourier Transform Infrared Spectroscopy. Fig. 2 shows the FTIR spectra of AC, AC/Ag nanocomposite, and AC/Ag/ TiO₂ nanocomposite. The sharp band at 512 cm⁻¹ is attributed to P vibration [18]. The modes at 980 cm⁻¹ and 1120 cm⁻¹ correspond to C-O asymmetric and symmetric stretching vibration [26]. The peak at 1384 cm⁻¹ is ascribed to the carboxylic group absorption (COOH) present at the surface. The wavenumber at 1640 cm⁻¹ is assigned to the bending mode of O-H vibration, which can occur due to the surface adsorbed water molecules [27]. The vibration peak of 2900 cm⁻¹ is consigned to C-H stretching vibration mode. The broad peak at 3400 cm⁻¹ is attributed to the O-H stretching vibration of water molecules. The vibrational mode at 777 cm⁻¹ is indorsed to the vibrational mode of Ag-O-C [28]. The vibration at 622 cm⁻¹ is described as the Ti-O stretching mode, which is distinctive of the formation of TiO₂ on activated carbon [29]. Compared to AC and AC/Ag nanocomposite, the O-H vibrational bands at 1640 cm⁻¹ and 3400 cm⁻¹ are presented in AC/Ag/TiO₂ nanocomposite is very broad and intense, which confirms that the AC/Ag/TiO₂ nanocomposite contains a large number of surface adsorbed hydroxyl (OH) species. These hydroxyl species play a vital part in the photodegradation process, and they can increase the degradation efficiency during the photocatalytic process.

3.3 Surface Morphological and Elemental analysis

The surface morphological and average size of the prepared materials were infra-red from SEM analysis. Fig. 3 represents the SEM images of prepared AC, AC/Ag nanocomposite and AC/Ag/TiO₂ nanocomposites. The SEM image (Fig. 3 (a)) reveals that the prepared activated carbon exhibits the irregular-shaped flake/sheet-like surface morphology with an average size of 50 to 100 nm. The dark and bright regions of AC/Ag composite in Fig. 3 (b) show the spherical-shaped particle aggregation due to silver nanoparticles presence over the surface of AC. The average size of the prepared AC/Ag nanocomposite is found to be around 30 nm. The homogeneous, smoother and compact needle-like particles are distributed on the surface of AC were observed in Fig. 3 (c) is attributed to the existence of TiO₂ on the AC surface. Also, some of the Ag particles are anchored on the surface of TiO₂ needles. The average diameter and size of the TiO₂ needles are in the range of 30 - 15 nm [30]. From the SEM image of AC/Ag/TiO₂ nanocomposite, the observed flake, sphere and one dimensional (1D) needles are responsible for the migrations of photo excited charge carriers on the surface of AC/Ag/TiO₂ nanocomposite; it can inhibit the electron-hole pair recombination rate during the degradation process. The element distribution of this AC/Ag/TiO₂ nanocomposite can be determined by EDX mapping on an EDX microanalysis system (Fig. 4 b). The signals for Si, Ag, and Ti elements are associated with the MMT, Ag and TiO₂ nanoparticles, respectively [31, 32]. Fig. 4 a, b shows EDX spectra of nanocomposites.

3.4 UV-Visible spectroscopy analysis

UV-Visible spectra of AC, AC/Ag and AC/Ag/TiO₂ nanocomposite were shown in fig. 5 a). The maximum absorption spectra of activated carbon reveal λ_{max} as 257 nm reveals π - π^* transition in carbon material [20]. The presence of silver nanoparticles reveals the absorption spectrum around 400 nm [33]. AC/Ag spectra do not reveal surface Plasmon resonance due to the incorporation of activated carbon. The AC/Ag/TiO₂ nanocomposite shows a wide absorption peak at 608 nm [14]. The observed result is well-matched with the previous report. The addition of titanium ions incorporated with silver ions reveals strong interaction between the orbit of TiO₂ and Ag. Strong absorption spectra were observed due to strong hybridization between the silver orbitals and the Ti 3d and O 2p bands near the Fermi level

[34]. The optical bandgap of the investigated nanocomposite was calculated using the Tauc plot. AC, AC/Ag and AC/Ag/TiO₂ nanocomposite reveals optical band gap value of 2.75 eV, 2.25 eV, and 1.99 eV respectively. The narrow bandgap of AC/Ag/TiO₂ nanocomposite acts as a better candidate material for active, visible light heterojunction with activated carbon [16]. Lower band gap value observed at AC/Ag/TiO₂ nanocomposite confirmed due to quantum confinement effect caused by nano dimensional state materials [35]. The bandgap values were well-matched with the crystallite sizes and particle sizes values. The obtained values are tabulated in table 2.

3.5 Transmission Electron Microscope analysis

TEM images of AC/Ag/TiO₂ nanocomposite are shown in Fig. 6. Morphology, and particle size values can be identified using the TEM image. TEM images of AC/Ag/TiO₂ nanocomposite reveal the needle-shaped structure with spherical pores due to presence of silver nanoparticles. The slight approximate surface area obtained on the surface of needles indicates the presence of carbon. The AC/Ag/TiO₂ nanocomposite expresses a particle size value of 24 to 36 nm. The intended results are highly correlated with the mean crystallite size value calculated from XRD. The spotted rings found in the SAED pattern shows the crystalline nature of composite.

3.6 Photocatalytic dye degradation analysis:

The photocatalytic activity of activated carbon (AC), AC/Ag and AC/Ag/TiO₂ nanocomposite was investigated against the photodegradation of methylene blue dye under Visible irradiation (Fig. 7-a). Initially the maximum absorbance peak obtained at 657 nm for methylene solution without catalyst. Maximum absorption occurs due to the n- π^* transition of MB. Activated carbon shows a maximum degradation efficiency of 79 % at the end of 120 Minutes. When visible light pass through the heterogeneous catalyst, electron excited from the valance band to the conduction band, generates positive holes and negative electrons on the surface of TiO₂. The electrons from the conduction band of TiO₂ react with Ag/AC catalyst surface to form the free radical OH $\cdot$ and the superoxide radicals O₂ $^{\cdot-}$ [37]. Free radicals such as O₂ $^{\cdot-}$ and OH $\cdot$ are responsible for the degradation of MB. During the reduction reaction, the methylene blue dye is converted to Leuco Methylene blue (LMB) [38]. On the other hand, the positive holes of titanium dioxide break down water molecules to form free radicals and negative electrons react with oxygen molecules to form superoxide anions. The carbon act as suitable electron acceptor, and titanium dioxide as a perfect donor under the light irradiations [39].

The decomposition of methylene blue dye after 120 minutes by Ag/AC catalyst results degradation efficiency of 84% while its 96% for Ag/AC/TiO₂ catalyst. The degradation efficiency of Ag/AC was much higher than Ag/AC/TiO₂ catalyst. Higher catalytic activity obtained due to larger surface area, less particle size and crystallite size, and excellent optical activity. The obtained result suggests that silver nanoparticles enhances the charge separation by trapping photoelectrons. Co-catalyst silver acts as electron sink and inhibit the recombination rate, quantum yield and enhances the absorption capacity for visible light due to Surface Plasmon resonance. The rate of kinetics of the catalyst were calculated from pseudofirst-order kinetics and their plotted spectrum was shown in Fig. 7.b. The possible mechanism of the catalyst against MB dye as shown in fig. 8. The addition of TiO₂ helps prolong the lifetime of the electron, and it has a high ability to break molecular bonding. Photocatalytic activity of as prepared nanocomposites reveals potential application for the removal of methylene blue, environmental and wastewater treatment [40,41].

Compared to our present study, the degradation efficiency increases from 84% to 96% for AC/Ag/TiO₂ composite. Photodegradation efficiency of AC/Ag/TiO₂ nanocomposites (96%) > AC/Ag nanocomposite (84%) > Activated carbon (79%) respectively. The enhanced photocatalytic activity in the composite could be assigned to reduction of electron-hole pair recombination, size, morphology and crystal structure of the nanoparticles. The present work compared with previous reported metal and metal oxide catalyst as tabulated in table 3.

3.7 Anti-bacterial activity:

In ancient times silver and silver samples have been used for its microbial activity. The possible reaction mechanism may occur 1) electrostatic attraction takes place between negative charge cell wall and positive charge nanocomposite. 2) effect of concentration may affect the cell wall of bacteria. In the present work, antibacterial activity was examined against *Bacillus subtilis* and *Escherichia Coli*. *E. coli* is a gram-negative pathogen and less susceptible to antibiotics and antimicrobial activity. *Bacillus subtilis* is a gram-positive bacterium found in soil. As expected no inhibition zone layers are observed in control. Among these bacteria reveals maximum zone inhibition value of 2.8 mm for *Bacillus subtilis* and *E. coli* bacteria has minimum zone value.

Fig. 9 a, b shows antibacterial activity of activated carbon, AC/Ag and AC/Ag/TiO₂ nanocomposite. Interaction takes place between positive ions from composite with negative bacterial cell wall enhances the antibacterial activity. The gram-positive bacteria displayed higher antibacterial activity than gram-negative pathogen [53, 54]. Activated carbon combined with silver and titanium composite acts as an excellent antimicrobial agent. The excellent antibacterial activity reveals the strong interaction between metal and metal oxide ions with cell membrane and proteins leads to increase permeability and consequently distribution and extravasation of intercellular content [55, 56]. Active materials exert their activity by contact with bacteria and get surface interaction between nanoparticles, increasing antibacterial activity. Antibacterial activity of investigated carbon and composites is applicable for biomedical application, wastewater treatment and other environmental applications.

4. Conclusion

In the present investigation, AC/Ag/TiO₂ nanocomposite were successfully synthesized by hydrothermal method by a low cost reducing agent jasmine flower extract. The crystalline nature was confirmed using XRD pattern and spotted rings in the SAED pattern. The functional group was identified using the FT-IR spectrum. The EDX spectrum shows as prepared material is contamination free. The prepared nanocomposite material reveals flake like structure. The biosynthesis method used in the study has vast advantages like cost effective, less toxicity, eco-friendly and highly bio safety. Furthermore, as prepared nanocomposite results excellent antibacterial against clinically important bacterial pathogens and exhibit excellent photocatalytic activity. Thus the prepared composite material is highly applicable for environmental waste water treatment, dye removal, drug delivery and food packages.

Declarations

Competing Interest

The authors declare we have no conflict of interest.

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Tables

Table. 1. The Average Crystallite Size, Dislocation Density, and Lattice Strain of the Photo catalysts

Photo catalysts	Average Crystallite Size (nm)	Dislocation Density (Lines/m ²)	Lattice Strain
AC/Ag	17.590	32.319*10 ¹⁴	20.614*10 ⁻⁴
AC/Ag/TiO ₂	11.496	75.667*10 ¹⁴	41.443*10 ⁻⁴

Table. 2. The Absorption range, Band gap value of the Photocatalysts

S.No	Sample code	Absorption range	Bandgap value	Crystallite size (nm) (XRD)	Particle size (nm) (DLS)
1.	AC	257	2.75 eV	-	196
2.	AC/Ag	400	2.25 eV	17.590	147
3.	AC/Ag/TiO ₂	608	1.99 eV	14.496	163

Table. 3 Comparative assessment of photocatalytic efficiencies of the metal/metal oxide nanocomposites

S.No	Nano catalyst	Synthesis routine	Testing dye	Illumination time (min)	Illumination source	Degradation efficiency (%)	Reference
1.	Fe ₃ O ₄ /RGO	Green synthesis	Phenol	150	Visible light	94.7	[42]
1.	CoFe ₂ O ₄ @ZnO-CeO ₂	Sono chemical green synthesis	Humic acid	100	Visible and UV light	97.2 72.4	[43]
1.	Ag/TiO ₂	Chemical deposition	Phenol	60	Visible	78	[44]
1.	Ag/TiO ₂	Electro spinning	Glucose	120	UV light	85.49	[45]
1.	Ag/TiO ₂	Hydrothermal	RhB	120	Sunlight	92	[46]
1.	CuO/ZnO	Precipitation	RhB Methylene blue	150	Sunlight	98.7 96.6	[47]
1.	TiO ₂	Green synthesis	Lead	17 hrs	UV light	75.5	[48]
1.	ZnS/CdS	Microwave assisted	Methylene blue	360	Visible light	73	[49]
1.	Mg/SnO ₂	precipitation	Methylene blue	90	Visible light	95.7	[50]
1.	CdS/TiO ₂	Hydrothermal	Methylene blue	180	Visible light	78	[51]
1.	Mg/ZnO	Auto combustion	Methyl orange	40	Visible light	30	[52]
1.	AC	Hydrothermal carbonization	Methylene blue	120	Visible	79	Present work
1.	Ag/AC	Hydrothermal	Methylene blue	120	Visible	84	Present work
1.	Ag/AC/TiO ₂	Hydrothermal	Methylene blue	120	Visible	96	Present Work

Figures

Figure 1

XRD patterns of AC, Ag/AC, and Ag/AC/TiO₂ nanocomposites

Figure 2

FT-IR spectra of AC, Ag/AC, and Ag/AC/TiO₂ nanocomposites

Figure 3

SEM images of a) AC, b) Ag/AC, c & d) Ag/AC/TiO₂ nanocomposites

Figure 4

Figure 5

UV-visible absorbance spectra of a) AC, Ag/AC and Ag/AC/TiO₂ nanocomposites, and Tauc plot of b) AC, c) Ag/AC, d) Ag/AC/TiO₂ nanocomposites.

Figure 6

TEM images and SAED pattern of Ag/AC/TiO₂ nanocomposites.

Figure 7

Photodegradation of methylene blue under visible irradiation a) degradation profile and b) kinetics plot.

Figure 8

Photo degradation mechanism of Ag/AC/TiO₂ nanocomposites.

Figure 9

(a-b) Antibacterial activity of *B. subtilis* and *E. coli*.