



Preparation, Microstructure and Performance of Activated FA / TiO₂-WO₃ Composite Photocatalyst

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Authors' contributions

This work was carried out in collaboration between all authors. Author MQ designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author YC managed the analyses of the study. Author QH managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The goal of this article was to preparation Fly ash(FA)/TiO₂-WO₃ Composite Photocatalyst based activation and modify of FA surface using simple chemical method. The FA carrier and catalysts were investigated through XRD, SEM/EDS and BET. The photocatalytic efficiency of composite photocatalyst was evaluated by degradation of methyl orange under UV irradiation. The results confirmed that the H₂SO₄ activation altered the surface structure and composition of FA, the specific surface area increased from 8.2 m²/g (Raw ash) to 15.5 m²/g (activation FA). The surface modification of FA was conducive to supporting photocatalysts powder by tetrabutyl titanate sol treating. The loading composite photocatalyst showed the higher photocatalytic degradation efficiency under UV irradiation. The decolorization efficiency can reach 97% when the TiO₂-WO₃ loading amount is wt5% in 30 min. The composite photocatalysts compared with raw FA, activated

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FA and modified FA, The results revealed that the photocatalytic degradation play main role after adsorption equilibrium. Furthermore, the photocatalytic mechanism and carrier effect were preliminary discussed.

Keywords: FA; TiO₂-WO₃; composite photocatalyst; microstructure; methyl orange (MO).

1. INTRODUCTION

In recent years, the application of the semiconductor photocatalysis for remedying the problem of chemical wastes in water has attracted much attention. In the most of semiconductor photocatalysts, the TiO₂ is considered as the most promising photocatalyst due to its excellent functionality, stability, low-cost and nontoxicity. However, in practical application, the nano-TiO₂ powder has a large band gap and it absorbs only a small portion of near ultraviolet region solar light [1-3]. Meanwhile, difficult to recycle, not suitable for flowing system. Therefore, on the one hand, many attempts have been devoted to improving the activity of TiO₂ and its photocatalytic efficiency under visible light, such as compound, doping ions, supported expensive metals and outfield assistant and so on [4,5]. On the other hand, the photocatalyst fixation is also a major research field.

Fly ash (FA) as the solid by-product of coal-fired power plants, the main components are silica, alumina, ferrous oxide, and calcium oxide with varying amounts of carbon, the chemical composition is difference due to the type, source and combustion condition. The chemical composition containing a variety of oxides with SiO₂, Al₂O₃, Fe₂O₃, CaO, MgO, K₂O, Na₂O, TiO₂ and so on. It was recognized to pose huge environmental problems (air, soil and water pollution, etc), therefore, more and more research are devoted to identifying various effective paths to use the fly ash [6,7]. Among them, FA particles as a novel type of photocatalyst carrier represent a highly promising alternative due to their high chemical stability, high surface area and high adsorption capacity. However, the FA particles surface were wrapped by the stability glass shell, its potential activity was influenced [8]. So, how to modify and activate the potential activity of FA, as a novel photocatalyst carrier, it has important practical significance to improve the added value and comprehensive utilization of FA [9].

In this work, the FA was first modified by acid dissolution method, in soaking process, the soluble alkaline oxides (K₂O, Na₂O, MgO, CaO)

and free inorganic component were removed from the raw FA into the solution, then, its surface was treated with butyl titanate sol, the modified FA was used as carrier for the immobilization of industrial nano-TiO₂-WO₃ photocatalyst. The composite photocatalytic (TiO₂-WO₃/FA) activity was investigated in the methyl orange dye and clarified based on X-ray diffraction (XRD), BET surface area (BET), scanning electron microscopy (SEM). The influence of key operational parameters, such as the phase, composition, surface microstructure has been as well considered.

2. EXPERIMENTAL

2.1 Reagent and Instrument

All chemicals were of reagent grade and were used without further purification. The FA was collected from the electro-filters of the thermal power plant in Hebei Province Baoding City (ASTM C618-05, China-2008). The TiO₂-WO₃ (WO₃, wt 3%) powder was commercial product purchased from Jiangsu Catalyst Co., Ltd.

The surface microstructure and surface elements of samples were characterized by using SEM(JSM-7500F, JEOL), XRD(Y-2000) and EDS(NARO, USA). Analysis of the as-prepared photocatalysts was carried out at room temperature with a Y-2000 apparatus using Cu target (Dandong ray instrument Co., Ltd. China). The BET surface area was determined using a Micromeritics Tristar II 3020 surface area and pore analyzer (Micromeritics, USA). The UV-Vis absorption spectra of samples were observed by TU-1900 UV-Vis spectrophotometer.

2.2 Activation and Surface Modification of FA

The acid activation of FA was conducted by mixing the ash with a 1M H₂SO₄ dissolution, the solution was under vigorous stirring for 4 h at 40°C, then, the wet FA was filtered, washed and dried. In order to obtain improved interaction between FA and photocatalyst, according to the

literature, the surface modification of FA was conducted by tetrabutyl titanate-ethanol-triethanolamine sol system. The acid activated FA was added to the configured sol for 2 h under magnetic stirring and aged 24 h. The FA particles were afterwards filtered, the obtained product is surface modified FA.

2.3 Preparation of Nano-TiO₂-WO₃/FA Composites Photocatalyst

The nano-TiO₂-WO₃ powder was mixed with 10 ml ethanol under an ultrasonic system for 1 h, then, the activated and modified FA was added to this solution and for the mixture was stirred for a further 2 h. The product was filtered and dried, finally, the samples were calcined in the muffle furnace at 450°C for 4 h. The TiO₂-WO₃/FA composite photocatalyst were prepared in the same way, the different weight rate photocatalyst were also as-prepared via the same method.

2.4 Photocatalytic Activity Test

The light source was provided by a 40 W ultraviolet light lamps (wavelength 2537 Å), which were placed above the reactor for 6 cm, methyl orange dye was used as a target reactant. The photocatalysts were added into 50 mL methyl orange solution (20 mg/L) under the magnetic stirring in the photo chemical reactor, after irradiation under different time period, by the way of taking the supernatant liquor, centrifuged and filtrated, the photocatalytic activity was tested by UV-vis spectrophotometer at 465 nm. The photocatalytic degradation rate (D) was calculated by the following formula: $D = (A_0 - A) / A_0 \times 100\%$, where A_0 and A denote the absorbance of the dye solution before and after photocatalytic treatment respectively.

3. RESULTS AND DISCUSSION

3.1 XRD Analysis

The phase structure and crystal form of different as-prepared samples are performed by X-ray diffraction. Fig. 1 shows the XRD patterns of the raw FA, activated and modified FA and composite photocatalysts. The phase composition of activated and modified FA (Fig. 1b) had not greatly change compared with the raw FA (Fig. 1a). The typical diffraction peaks of quartz, mullite are evidenced in the patterns at 16.39°, 26.01°, 26.27°, 33.23°, 26.58°, 20.86° (Al₆Si₂O₁₃:15-0776; SiO₂:46-1045), the diffraction

peak position and intensity have changed partly. Fig. 1c shows the XRD pattern of composite photocatalyst. It can be seen that the new diffraction peaks at 25.80°, 48.04° and 55.07° are clearly appeared, which can be assigned to the anatase TiO₂ (21-1272) and WO₃ (20-1324) respectively. It is mainly due to the photocatalyst (TiO₂-WO₃) onto the FA surface. In addition, the photocatalyst after the photocatalytic process were comparatively investigated (Fig. 1d). Compared with Fig. 1c, the XRD spectra showed without significant changing, the composite photocatalyst was confirmed stability.

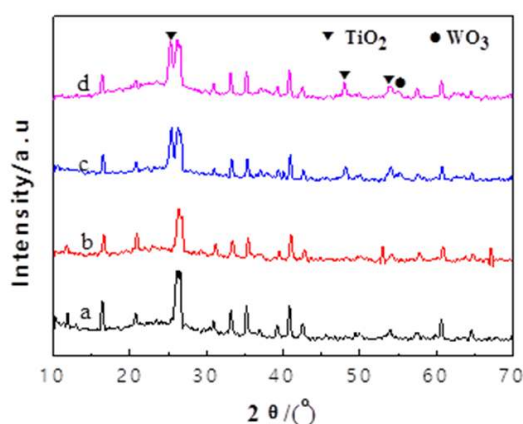


Fig. 1. XRD spectra of samples (a: Raw FA; b: Activated and modified FA; c: composite photocatalyst; d: After photocatalysis)

In order to investigate the effect of H₂SO₄ activated FA, the BET surface area was measured, the result showed that the specific surface area of activation FA was 15.5 m²/g, which is larger than that of raw FA (8.2 m²/g). The reason may be H₂SO₄ activation altered the surface structure and composition of FA. In soaking process, the soluble alkaline oxides (K₂O, Na₂O, MgO, CaO) and free inorganic component were removed from the raw FA into the solution, the higher roughness and pores were re-formed in acid, resulting in the observed higher specific surface area.

3.2 SEM and EDS Analysis

The surface morphologies of as-prepared samples were investigated by SEM. The raw FA morphology was shown in Fig. 2a, as can be observed in Fig. 2a, the raw FA presents large particle aggregates with spherical and amorphous particle, the small glass beads were

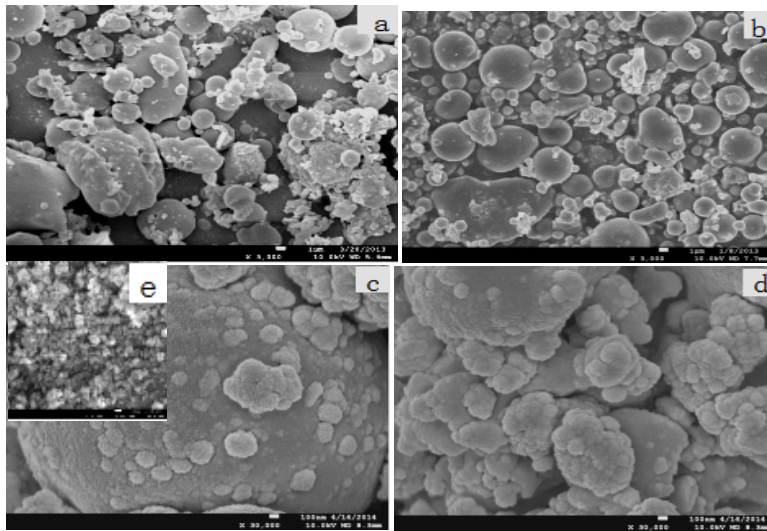


Fig. 2. SEM photos (a: raw FA; b: activated FA; c: FA/TiO₂-WO₃; d: FA/TiO₂-WO₃ after photocatalysis; e: TiO₂-WO₃)

adhered to big particle surface. The activated FA image was shown in Fig. 2b, it can be clearly observed that the spherical particle was dispersion with a smooth surface. Fig. 2c, d show the surface morphology of composite photocatalyst before and after photocatalysis process, from Fig. 2c, we can see that the surface of FA became rougher, which indicates some nano-TiO₂-WO₃ particles coating on the surface, the catalysts size was about 20-30 nm (Fig. 2e). In Fig. 2d, after photo degradation process, a certain amount of photocatalyst particles was maintained on the FA surface, the stability and activity of composite photocatalyst were proved.

The chemical constituents of samples were revealed by EDS analysis. The typical spectra were shown in Fig. 3. The result show that raw FA mainly consisted of Si, Al, and O elements,

and small amounts of elements such as Ca, Ti, Fe, Mg, etc (Fig. 3a), compared with Fig. 3b, it can be clearly seen increasing Ti, W element peak in the composite photocatalyst. The combined results of SEM, it was further confirmed that the photocatalyst was well-loaded on the FA particles surface by activation and modification process.

3.3 Photocatalytic Activity Studies

In order to evaluate photocatalytic activity of composite photocatalyst, the photocatalytic degradation of MO (20 mg/L) was carried out under 40 w UV light irradiation [10]. The other condition was fixed with the 50 mL MO solution, 200 mg composite photocatalyst and 30 min time. The photocatalytic activity was tested at the different TiO₂-WO₃ loading capacity. For investigating carrier effect of FA, firstly, the

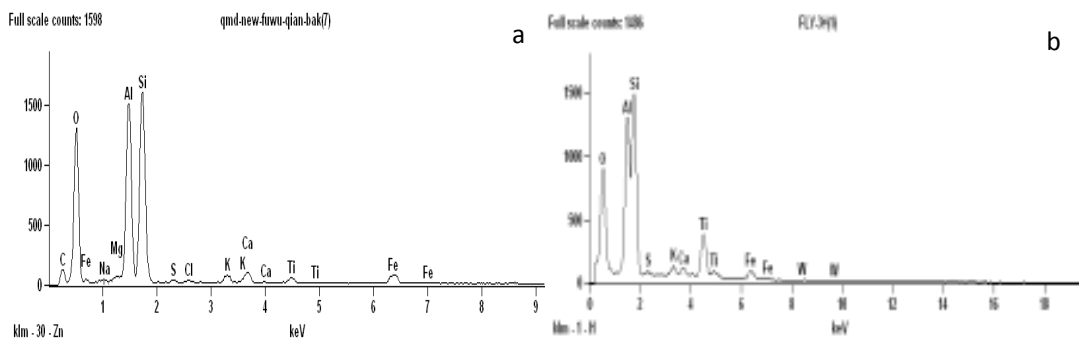


Fig. 3. EDS spectrums of samples (a: raw FA; b: FA/TiO₂-WO₃/FA)

decolorization performance of activation and modify FA was tested under dark condition. The results show decolorization ratio is about 40%. This result confirmed that the FA carrier possesses preferably adsorption performance. The Fig. 4 shows the photocatalytic activity of composite photocatalyst at the different $\text{TiO}_2\text{-WO}_3$ amount supported on FA. It can be seen that the $\text{TiO}_2\text{-WO}_3$ loading capacity has a great influence on the photocatalytic decolorization performance. It may be noted that the decolorization efficiency is about 58%, when have not $\text{TiO}_2\text{-WO}_3$ composite photocatalyst. The reason was attributed to excitation and modify FA by H_2SO_4 and titanium sol [11]. With the increasing of the $\text{TiO}_2\text{-WO}_3$ loading amount in the range wt0.5%-5%, the decolorization efficiency increases from 76% to 97% after 90 min. However, further increasing the catalyst dosage from wt6%-10% resulting in a slight decrease in the decolorization efficiency. The reason may be a more photocatalyst suspension may lead to decrease of its transparency resulting in less efficient radiation penetration [12]. In order to further investigate the decolorization efficiency, the wt0.5% ($\text{TiO}_2\text{-WO}_3/\text{FA}$) composite photocatalysts was used to compare with raw FA, activated FA and modified FA at different photocatalytic degradation time. The experimental results were shown in Fig. 5, under the same condition, the decolorization rate of activation FA exhibit higher decolorization than raw FA in the first 10 min. The decolorization rate was about 35% and 42% respectively, with the increase of time, the decolorization rate was stable, it was inferred that the adsorption process played a dominant role and reach adsorption-

desorption equilibrium in 10 min. This results show that the adsorptive property of activation FA possess have good discoloring performance than raw FA due to the higher specific surface area. Compared with the modify FA by tetrabutyl titanate sol, the degradation and discoloring rate can reach about 50% in 10min, afterward, the discoloring rate emerge slowly increase with time increasing. The reason for the result was that the anatase TiO_2 film supported on FA surface, the photocatalytic degradation play its role effectively after adsorption equilibrium. In addition, it's worth noting that the highest degradation activity was shown in Fig. 5. A significant increase in photocatalytic activity is exhibited by the as-prepared composite photocatalysts, the degradation and discoloring rate reach over 80% in 10 min, the decolorization rate appeared gradually increasing with time extension and reached more than 97% at 90 min under UV radiation. The results indicate that the as-prepared composite photocatalysts displayed excellent photocatalytic performance. The reason may be attributed to the doping WO_3 presence in composite photocatalysts. The TiO_2 and WO_3 belong to metal semiconductor with different electronic structure and energy level structure. In photocatalytic process, The TiO_2 play an important role due to its higher photocatalytic performance under UV light, when the TiO_2 was integration with WO_3 semiconductor. The TiO_2 and WO_3 simultaneously occur interband transitions under the UV irradiation [13]. The photoinduced electron transfer from the TiO_2 surface to the lower energy level WO_3 due to different energy levels, the WO_3 induced hole

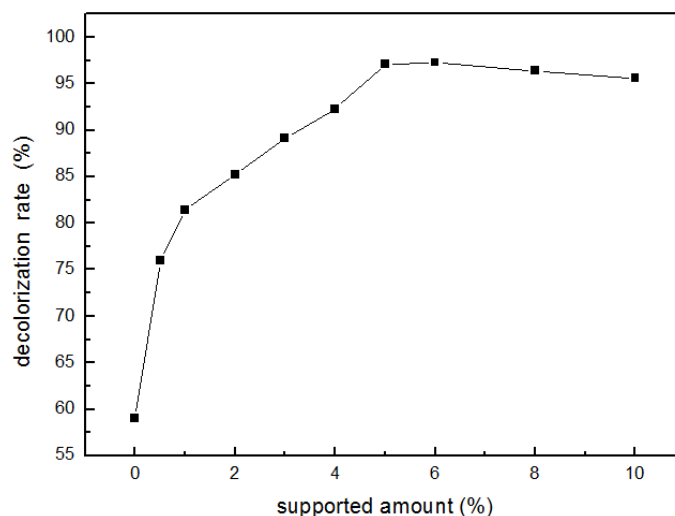


Fig. 4. Effect of the different $\text{TiO}_2\text{-WO}_3$ supported amount on decolorization rate

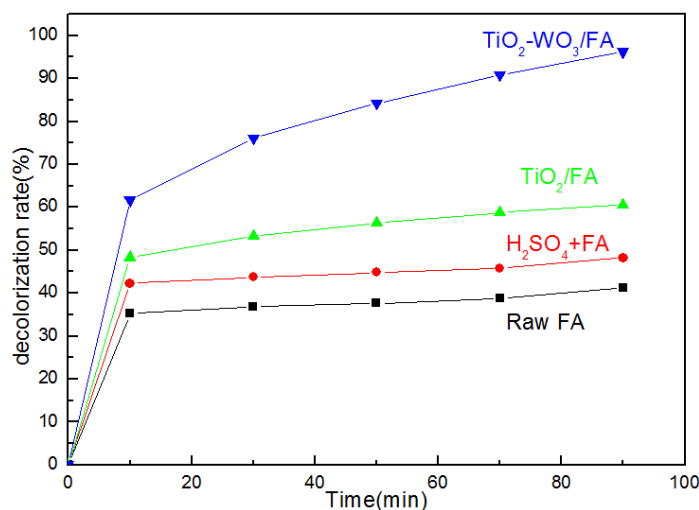


Fig. 5. Effect of decolorization rate at photocatalytic degradation time

was migrated to the higher TiO₂ valence band, this process suppressed the electron-hole pair recombination [14-17]. On the other hand, the photocatalytic process was mainly carried out on the catalyst surface, a larger specific surface area FA carrier had been confirmed by activating and modifying process, meanwhile some elements (Fe, S, etc) of FA carrier may be enhanced photocatalytic activity due to improve the absorption threshold and reduce the hole-electron pair recombination. In addition, the composite photocatalysts was carried out for 5 times, the degradation and discoloring rate reached to 95% in 90 min. So, the as-prepared composite photocatalysts showed the higher photocatalytic degradation efficiency and stability.

4. CONCLUSIONS

The surface of FA carrier was activated and modified by a simple wet-chemical method. The results showed that the specific surface area of activation FA was 15.5 m²/g, which is larger than that of raw FA (8.2 m²/g) by H₂SO₄ soaking and the modified FA was more beneficial to loading photocatalysts via tetrabutyl titanate sol processing. The as-prepared TiO₂-WO₃/FA composite photocatalysts showed the higher photocatalytic degradation efficiency under UV irradiation. With the increasing of the TiO₂-WO₃ loading amount in the range wt0.5%-5%, the decolorization efficiency increases from 76% to 97% after 30 min. Further increasing the catalyst dosage from wt6%-10% resulting in a slight decrease in the decolorization efficiency. The wt0.5% (TiO₂-WO₃/FA) composite photocatalysts compared with raw FA, activated FA and

modified FA. It indicated that the decolorization rate appeared gradually increasing with time extension and reached more than 97% at 90 min. The results revealed that the photocatalytic degradation play main role effectively after adsorption equilibrium. The result showed that the specific surface area of activation FA was 15.5 m²/g, which is larger than that of raw FA (8.2 m²/g).

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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