



Electrochemical Analysis of Polyvinyl Alcohol/Magnetic Iron Oxide Composite Nanofibers for Supercapacitor Applications



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Abstract

The supercapacitor is an achievable electrochemical energy storage device with exceptional cycle stability, quick charging time, and high power density, allowing it to be used in a variety of applications. The electrode, as a major component, has a significant impact on the specific capacitance and efficiency of the supercapacitor. To improve the conductivity the Magnetic iron oxide nanoparticle was added to the PVA nanofibers. The magnetic iron oxide nanoparticles were prepared by using Ferric Chloride and iron (II) sulfate heptahydrate in alkaline medium. The morphology and chemical composition of the polyvinyl alcohol (PVA) nanofibers and polyvinyl alcohol/magnetic iron oxide PVA/Fe₃O₄ nanocomposite fibers were characterized by Scanning electron microscopy (SEM), thermogravimetry (TGA), energy dispersive X-ray (EDX) analyses and FTIR analysis. Using Cyclic Voltammetry (CV), the electrochemical characteristics of PVA nanofibers and PVA/Fe₃O₄ composite nanofibers as a supercapacitor electrode material was investigated. PVA nanofibers and PVA/Fe₃O₄ nanocomposite were made by electrospinning in this work and then investigated as electrode materials for supercapacitors. The experimental results show that the PVA/Fe₃O₄ nanocomposite has a higher specific capacitance of 168 F/g than the PVA nanofibers (5.6 F/g). According to the findings PVA/Fe₃O₄ nanocomposite with high specific capacitance have a prospective use as supercapacitor electrodes.

Keywords: Supercapacitor, Transition metal oxide, PVA nanofibers.

1. Introduction

A supercapacitor, or electrochemical capacitor, is an electrical device with extremely high reversible charge storage and transport capabilities. In different energy storage devices, supercapacitors have a high specific capacitance, rapid charge/discharge rate, a large power density, and a long cycle life [1]. It has several potential uses in wind energy generation, transport systems, wireless transmission, electrical devices, and other disciplines [2]. These gadgets have piqued the interest of academics worldwide, resulting in a great number of study papers in the relevant subject. Supercapacitors have a longer lifespan, are resistant to temperature fluctuations, and are naturally safe. As a consequence, they are more trustworthy as well as charging faster. Supercapacitors are now used mostly in heavy machinery and other high-power devices [3]. Supercapacitors are classified into two

categories depend on how they store charge: Electrochemical double layer capacitors (EDLCs), in which capacitance is increased and generated by charge deposits at the electrode-electrolyte interface; moreover, pseudocapacitors, which involve capacitance in charge transfer through reversible faradaic processes on the electrode surface. As seen in (Figure.1), supercapacitors are generally constructed of two metal electrodes (parallel panels) isolated by a dielectric. The dielectric is a non-conducting layer that is placed between the parallel panels of the metal electrode substance [4]. Because the features of electrode materials influence supercapacitor operation, it is vital to create novel materials and enhance the efficiency of current substances [5]. Electrodes, being a key component of supercapacitors, have a significant impact on the specific capacitance and performance of

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supercapacitors. Transition metal oxides and conductive polymers are commonly used to make supercapacitor electrodes [6], [7].

Electrospinning is well recognized for being an appealing, cost-effective process capable of producing continuous nanofibers with a tiny diameter and a large surface area. Polymers such as polyvinyl alcohol (PVA), polyvinylpyrrolidone (PVP), and polyacrylonitrile (PAN) have recently been widely used in the electrospinning process to produce nanofibers. Nonetheless, in comparison to other polymers, PVA has received considerable attention and is useful for a wide range of applications, particularly in electrochemical equipments, because of its high-quality mechanical features, ecological friendliness, and excellent binding characteristics that promote greater adhesion to porous and water-adsorbent surfaces [8]. As a result, PVA solutions may be utilized in electrospinning to create ultrafine separation screens and biodegradable mats [9]. Recently, supercapacitors using polyvinyl alcohol (PVA) polymers have been developed [8], [10], [11, 12].

Yasin Altin and Ayse Celik Bedeloglu created porous carbon nanofiber (PCNFs) from hybrid nanofiber of polyacrylonitrile (PAN) and polyvinyl alcohol (PVA) with variable ratios of combining and employed them as independent, flexible, highly efficient electrodes for supercapacitors. PCNFs outperformed neat carbon nanofibers (N-CNF) in terms of specific capacitance and electrochemical performance. The specific capacitance of the EK5 PCNF (67/33 PAN/PVA wt ratio) was 157 F/g at a scan rate of 5 mV/s in 1 M H₂SO₄, whereas the specific capacitance of the N-CNF was 96 F/g. Furthermore, at a current density of 2 A/g, the PCNF demonstrated remarkable cyclic stability, with no loss of performance after 2500 charge and discharge cycles. Consequently, PCNFs that are independent, flexible; moreover, excellent efficiency are great materials for supercapacitor electrodes in flexible energy-storage systems. Mohd Abdah M. A. et. al [8] integrated electrospinning and electrodeposition procedures were used to create conducting nanofibers made of poly(vinyl alcohol) (PVA)-graphene oxide (GO) nanofiber coated with poly(3,4-ethylenedioxythiophene) (PEDOT) for supercapacitor applications. The creation of smooth cross-linking nanofibers without beads demonstrated that GO was dispersed evenly in PVA with an average diameter of 117±32 nm. When compared to PEDOT (167.92 F/g) and PVA/PEDOT (182.73 F/g), the PVA-GO/PEDOT nanocomposite had the greatest specific capacitance (224.27 F/g). PVA-GO/PEDOT nanocomposite demonstrated 1.8V broad working potential windows, which can greatly improve capacitive behavior. At 1.0A/g current density, the

PVA-GO/PEDOT nanocomposite likewise displayed better performance, with energy density and power density of 9.58Wh/kg and 304.37 W/kg, respectively. The PVA-GO/PEDOT nanocomposite had the lowest charge transfer resistance (R_{ct}) and equivalent series resistance (ESR), showing superior charge propagation behavior at the interfacial region. The composite retains 82.41% of its capacity after 2000 CV cycles; however, this declines to 11.27% after 5000 cycles due to swelling and shrinking of the electrode material during the charging and discharging operations. Developing a novel technique to efficiently avoid MXene nanosheet restacking will have a substantial influence on the design of flexible supercapacitor electrodes. Using sol-gel and freeze-dried techniques, Shuqing Cao et. al [13] create a new Ti₃C₂T_x/polyvinyl alcohol (PVA) porous sponge with 3D-linked architectures. This Ti₃C₂T_x/PVA porous sponge serves as a template for in-situ polyaniline (PANI) polymerization, and the resulting PANI@Ti₃C₂T_x/PVA hydrogel composite is employed as flexible supercapacitor electrodes. PVA 1D conductive polymer chains might improve the interlayer gap of Ti₃C₂T_x nanosheets, exposing additional electrochemical active sites. The PANI@Ti₃C₂T_x/PVA hydrogel composite supercapacitor shows both double-layer capacitance and pseudocapacitance characteristics. At 2Am⁻², this supercapacitor has a maximum area-specific capacitance of 103.8mFcm⁻², a maximum energy density of 9.2 Wh.cm⁻², and an optimal power density of 800μWcm⁻². The capacitance of this supercapacitor practically never changes when bent at different angles. Furthermore, after 10,000 charge/discharge cycles, the supercapacitor retains 99% of its capacitance. PANI and Ti₃C₂T_x/PVA composites' synergistic impact may increase the number of reactive sites and offer effective channels for ion diffusion and electron transport. Poonam Siwach and et. al [14] used chemical procedures to generate thin sheets of nickel cobalt oxide and polyvinyl alcohol nanocomposite (NCO-PVA). Cyclic voltammetry, galvanostatic charge-discharge, and impedance spectroscopy experiments are performed on a 1 M Na₂SO₄ neutral aqueous electrolytic solution to evaluate electrochemical performance. A symmetric supercapacitor with a specific capacitance of 50 Fg⁻¹ and an energy density of 18.9 Whkg⁻¹ has also been created utilizing NCO-PVA sheets as the electrodes. The findings show that the produced nanocomposite films have sufficient potential for supercapacitor device manufacturing, particularly flexible supercapacitors. Because of ozone depletion and environmental concerns, Shashank Shekhar and et. al [15] are creating eco-friendly and cost-effective energy storage systems is imminent. Biopolymer nanocomposites are the most

promising candidate for avoiding dangerous conditions. Chemical functionalization of graphene oxide (GO) is required to minimize nanoparticle aggregation and aid in end-use applications. The magnetic stirring approach is used to generate a poly(vinyl alcohol) and chitosan biocomposite, which is then ultrasonically dispersed. The goal is to stress the use of metal-free bionanocomposite materials in order to utilize and improve the electrical characteristics of the resulting product. The main disadvantage of chitosan is its poor mechanical strength, which can be compensated for by using GO and polyvinyl alcohol. Nanomaterials have attracted many research interests recently because of the growth of nanoscience. Nanomaterials might be incorporated into the PVA hydrogel matrix to improve its performance. Silver nanoparticles, titanium dioxide nanoparticles, carbon nanotubes (CNTs), CdSenanorods, Silica nanoparticles, gold nanoparticles, graphene oxide (GO) nanotubes, and graphene nanotubes are examples of common nanomaterial [16]. In addition to super capacitive uses, metal oxides (MOs) are used in solar cells as catalysts for oxygen evolution processes (OER), oxygen reduction reactions (ORR), hydrogen evolution reactions (HER), sensors, storage systems, and other domains. Because of their half-filled d orbital, they may exist in several oxidation states; they are the chosen material for catalytic applications. MOs like IrO_2 , Fe_3O_4 , RuO_2 , NiO , MnO_2 , Co_3O_4 , and others have been extensively researched for supercapacitor devices because of their high storage capacity, chemical stability, and changeable valance [14]. In comparison to other transition metal oxides (TMOs), Fe_3O_4 has received a lot of attention due to its better conductivity, increased theoretical capacity (926 mAhg^{-1}), nontoxic properties, natural availability, ecologically friendly features and affordable costs [17]. Recently, supercapacitors using PVA and Fe_3O_4 have been developed [18]. Mustafa Aghazadeh et al. created ultra-fine nanoparticles of magnetite iron oxide (Fe_3O_4) using PVA-aided cathodic electrosynthesis. In an aqueous electrolyte containing $0.005 \text{ M Fe}(\text{NO}_3)_3/\text{FeCl}_2$ and 0.1 g/L PVA , Fe_3O_4 was precipitated on a stainless steel cathode. Using cyclic voltammetry (CV), electrochemical impedance spectroscopy (EIS), and charge-discharge, the electrochemical behavior of the generated ultra-fine nanoparticles was examined. The electrochemical Information collected revealed that the produced Fe_3O_4 nanoparticles had acceptable charge storage capabilities, with a specific capacitance equals 195.8 Fg^{-1} , and they retained around 94% of their original capacity after 3000 cycles at the current usage of 0.5 Ag^{-1} . Amir Elsaidy and et. al [19] produced a composite consisting of clusters of iron oxide ($\text{Fe}_3\text{O}_4\text{-Fe}_2\text{O}_3$) nanoparticles and reduced graphene oxide (rGO) for a high-

performance supercapacitor electrode using a simple one-step solvothermal manufacturing process. The $\text{Fe}_3\text{O}_4\text{-Fe}_2\text{O}_3/\text{rGO}$ nanocomposite demonstrated much better specific capacitance than rGO or bare clusters of $\text{Fe}_3\text{O}_4\text{-Fe}_2\text{O}_3$ nanoparticles. Specific capacitance values of 100 Fg^{-1} , 250 Fg^{-1} , and 528 Fg^{-1} were reported for iron oxide nanoparticle clusters, rGO, and the hybrid nanostructure, respectively. The synergistic interaction between the layers of graphene oxide and the clusters of iron oxide nanoparticles may be responsible for the composite material's improved electrochemical performance. The close contact between the two phases eliminates the interface, allowing for easy electron transport, which is essential for achieving high specific capacitance and, as a result, increased charge-discharge duration. After 3000 cycles of performance measurement, the composite material retains 110% of its original capacitance, making it a suitable choice for supercapacitors. Magnetic $\text{Fe}_2\text{O}_3@\text{SnO}_2$ heterostructures were produced by Morteza Safari and et. al [20] using the sol-gel electrospinning process at calcination temperatures of 450 and 600 °C. The electrochemical performance of $\text{Fe}_2\text{O}_3@\text{SnO}_2\text{-450}$ and $\text{Fe}_2\text{O}_3@\text{SnO}_2\text{-600}$ nanofibers as active materials coated onto Ni foams (NF) was tested in three and two-electrode configurations in a 3 M KOH electrolyte solution. After 3000 cycles, the $\text{Fe}_2\text{O}_3@\text{SnO}_2\text{-600/NF}$ electrode has a high specific capacitance of 562.3 Fg^{-1} at a current density of 1 Ag^{-1} and good cycling stability with 92.8% capacitance retention at a high current density of 10 Ag^{-1} . The $\text{Fe}_2\text{O}_3@\text{SnO}_2\text{-600/activated carbon}$ asymmetric supercapacitor device has a maximum energy density of 50.2 Whkg^{-1} and a power density of 650 Wkg^{-1} when built. The findings show that $\text{Fe}_2\text{O}_3@\text{SnO}_2\text{-600}$ is a viable electrode material for supercapacitor applications. Rajesh Kumar and et. al [21] created nanostructured composites with a distinct shape using dry microwave irradiation for use in supercapacitor electrodes. The hybrid material's microstructure was composed of reduced graphene oxide (rGO) nanosheets that were uniformly coated by almost uniform-sized, faceted Fe_3O_4 nanoparticles. Graphite oxide was reduced throughout the production, while $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ was concurrently degraded into Fe_3O_4 nanoparticles. The surface shape, flaws in the rGO nanosheets caused by the addition of Fe_3O_4 nanoparticles, and specific surface area of the as-synthesized materials has all been investigated. When evaluated in 1M KOH electrolyte, the electrode material provided a specific capacitance of 771.3 F/g at a scan rate of 5 mV/s . Furthermore, there showed a high stability to continuous charge/discharge cycling, with 95.1% capacitance retention after 5000 cycles. The synthesis method used in this study might be used to similar composite electrodes based on layered conductive structures and metal oxides.

Thirumurugan Arun and et. al [22] create A simple chemical oxidation process was used to create octahedral-shaped Fe_3O_4 and Fe_2O_3 nanoparticles. Using a sugar solution as a carbon source, the magnetic nanoparticles were surface modified with carbon. The carbon-modified octahedral-shaped Fe_3O_4 nanoparticles produced had a higher saturation magnetization of 87emu/g. Furthermore, the carbon-modified magnetic hybrid nanoparticles were used as a negative electrode material in supercapacitor applications, yielding a high specific capacitance value of 274 F/g for post-annealed samples. The increased specific capacitance value is attributable to the carbon percentage in the hybrid material, which might be increased further by increasing the carbon fraction. The cycle stability performance was evaluated with 5 A/g and demonstrated 83% retention after 5000 cycles.

This paper describes a simple electrochemical approach for producing ultra-fine iron oxide nanoparticles that will be used in future versions of energy storage applications. The electrospinning combination of PVA and Fe_3O_4 nanoparticles is regarded as a unique composite nanofiber in this work, and it investigates how well they operate as supercapacitors. PVA nanofibers were electrochemically spun concurrently to entrap Fe_3O_4 nanoparticles. Scanning electron microscopy (SEM), Fourier transform infrared spectroscopy (FTIR), thermogravimetric (TGA), and electron dispersive X-ray spectroscopy (EDX) were used to evaluate the composite nanofibers. Using cyclic voltammetry (CV), the capacitance performance of the composite nanofiber electrode was then evaluated.

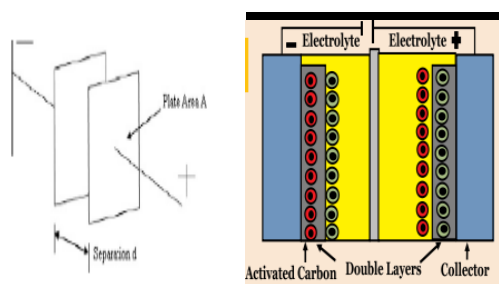


Figure.1. basic construction diagram of a super-capacitor.

2. Experimental

2.1. Materials and Measurements

Chemicals of reagent grade were obtained from the relevant sources: Ferric Chloride (FeCl_3 , reagent grade, 97%), iron(II) sulfate heptahydrate ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$, reagent grade, 99%), polyvinylalcohol (PVA, reagent grade, MW=85000 -124000), hydrochloric acid (HCl, reagent grade, 37%), sodium hydroxide (NaOH, reagent grade, 99%), Potassium Chloride (KCl, reagent grade, 99.0%). All analytical-grade

compounds were purchased from Sigma-Aldrich (Darmstadt, Germany) and used exactly as provided.

2.2. Instruments

(Burker, TENSOR 27-series FTIR, Germany) were used to obtain Fourier transform infrared (FT-IR) spectra of all the produced components in the 400–4000 cm^{-1} range at Tanta University's central laboratory. Thermal stability, maximum degradation temperature, and change in mass with an increase in temperature were all measured for the samples using a Perkin Elmer 4000 thermal analyzer with a heating rate of 10.0 deg./min in the range of 50–800 °C at polymer research group laboratory, faculty of science, Tanta University. Cyclic voltammetry (CV) measurement was measured for all samples using a computer-controlled potentiostat/ galvanostat model CS3104 (China) in microanalysis unit at Faculty of Science, Tanta university. EDX and SEM were examined for chosen sample by using JEOL Japan, JSM 6510 LV at Faculty of Agriculture, Mansoura University.

2.3. Synthesis of Magnetic Iron Oxide Nanoparticles

Ferric and ferrous ions were co-precipitated in an alkaline solution to create magnetic Iron nanoparticles (MINPs). MINPs were produced by the following method: In 50 ml of a 0.5 M HCl solution, 6.5 g of FeCl_3 and 5.56 g of $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ were dissolved, representing a 1:2 ($\text{Fe}^{2+}/\text{Fe}^{3+}$) molar ratio. After that, 500 ml of 1.5 M NaOH was then gradually added to the solution while vigorously mixing (600 rpm) with a mechanical stirrer and heating to 80 °C. The pH of the reaction medium was 14 as well. The final step produced a dark precipitate of Fe_3O_4 that appeared right away. After adding iron salts, the reaction happens quickly and magnetite nanoparticles are visible right away. By placing a magnet next to the black precipitate, the paramagnetic was measured in-situ. The precipitant separated in the magnet's magnetic field, while the pH of the solution was brought to neutral by decanting the supernatant liquid multiple times with distilled water. The precipitant was separated from its solution and dried out in a drying device at 50 °C for 4 hours before being kept at room temperature overnight. This produced the MNPs in powder form. MNPs were acquired as a result. SEM was used to measure the particle size [23].

2.4. Preparation of the polyvinylalcohol nanofiber

A 10 wt % of PVA solution was produced as follows: 1 g of PVA was dissolved in 10 ml of distilled water and stirring continuously for 2 hours at 90 °C. The polymer solution placed inside of a plastic syringe. The negative electrode (cathode) was linked

to a metallic collector that was coated in aluminum foil, and the positive electrode (anode) was connected to the syringe tip. In addition to the applied potential being set at 10 kV, the distance between the syringe tip and the collector was preset at 15 cm [24].

2.5. Preparation of nanofiber composite by electrospinning technique

A 0.76 wt % of Fe₃O₄ and 7.63 wt % of PVA solution was prepared as follows: 0.1 g of Fe₃O₄ nano powder in 12 ml deionized water at 90 °C by using mechanical stirrer. PVA 1g was added to Fe₃O₄ dispersion solution under stirring by using stainless steel mechanical stirrer. The mixture heated for 1 h at 90°C with stirring. The blend was stirred for 2 h at 90 °C. After that, the composite solution was placed into a 10 mL plastic syringe with a 0.4 mm needle diameter. The solution was subjected to a highly voltage of 13 kV with a tip-collector separation of 15 cm, and fiber accumulated on the plane collector [25].

2.6. Electrochemical Measurements

Following the electrospinning research described above, a supercapacitor cell was constructed employing multi-walled nanofiber sheets as an active material and aqueous KCl (1M) as an electrolyte. Aluminum foil was utilized as the current collector supported by using glass slide. Filter paper was used as a separator between electrodes contains the electrolyte. The potentiostat was used to test the cell, and a cyclic voltammetry CV test was performed to monitor the cell's behavior. Working and reference electrodes were connected to the two poles of a supercapacitor. Using CV technique, electrochemical measurements of metal oxide and nanofiber covered electrodes were investigated. An electrolyte of 10 mL of a 1 M KCl solution was added to the electrochemical cell. CV measurements in the range of 0.30 V to 0.60 V were performed utilizing a three-electrode setup comprising a working electrode, a reference electrode, and a counter electrode at a scan rate of 100mVs⁻¹. 1M KCl solution served as the electrolyte medium for the CV measurements. Peak currents of voltammograms produced by electrodes as a consequence of CV measurements are compared. Specific capacitance (C_s) values were calculated for

PVA nanofiber and PVA/Fe₃O₄ composite nanofiber electrodes using the following equations (1). Expressed here, v : scan rate (mVs⁻¹), ΔV : range of applied potential (V), m : mass of sample on the electrode surface (mg).

v : scan rate equals to 0.05 mV/s, ΔV : range of applied potential (V) equals to 0.5, m : mass of sample on the electrode surface (mg) equals to 0.01 and area under curve equals to 0.0014 for PVA nanofiber. Moreover, v : scan rate equals to 0.05mV/s, ΔV : range of applied potential (V) equals to 0.5, m : mass of sample on the electrode surface (mg) equals to 0.01 and area under curve equals to 0.042 for PVA/Fe₃O₄ composite nanofiber.

$$C_s = \frac{\text{area under curve}}{m \Delta V v} \quad (1)$$

3. Results and Discussion

3.1 Thermal gravimetric analysis of polymers

A TGA study of PVA nanofibers and PVA/Fe₃O₄ composite nanofibers was performed (in an inert nitrogen environment) to observe the differences in thermal stability between the materials. In (Figure.2), It is proven that PVA nanofibers is degraded faster than PVA/Fe₃O₄ composite nanofibers and the total mass loss was observed between 30 and 900°C as 24.945 and 22.722 % for PVA and PVA/Fe₃O₄ composite nanofibers, respectively. Four sections of the TGA spectra were analyzed. In the first region, PVA exhibited 2.55 % weight loss whereas PVA/Fe₃O₄ showed 2.12 % weight loss in the same region. At the second region 83.86 and 71.06 % weight losses observed. At the third region 8.32 and 10.83 % weight losses observed and finally at the fourth region 5.05 and 6.88 % weight losses were observed respectively for PVA nanofibers, PVA/Fe₃O₄ composite nanofibers. The inclusion of Fe₃O₄ nanoparticles to the PVA nanofibers structure promoted thermal stability, one of the advantages of supercapacitors.

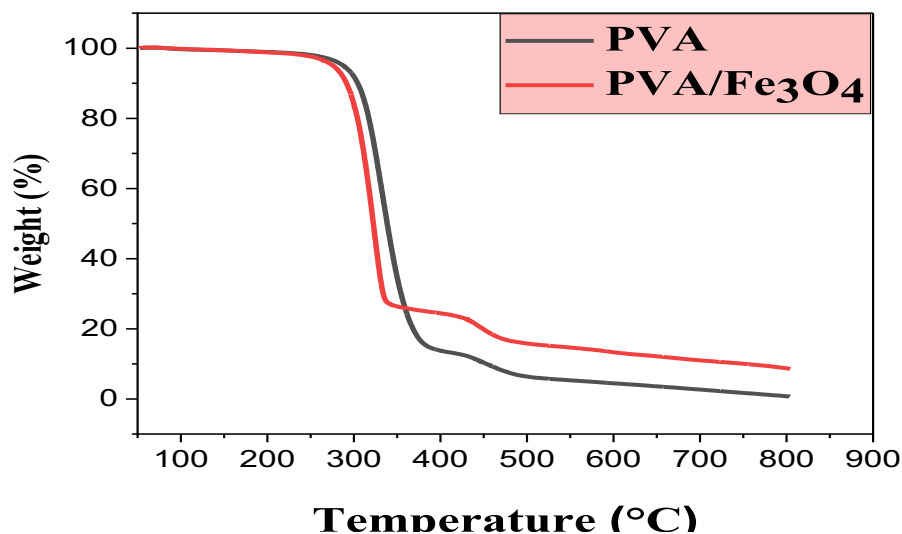


Fig. 2. TGA measurements of PVA and PVA/Fe₃O₄ composite nanofibers.

3.2 FT-IR analysis of Polymers

The FTIR of the composite was measured with the aim of determining the functional groups [26]. The FTIR spectra of PVA and PVA/Fe₃O₄ composite nanofibers structures are presented in (Figure.3). The FTIR spectra of PVA and PVA/Fe₃O₄ composite nanofibers give extensive information on peak positions and peak intensities. PVA nanofibers compound and PVA/Fe₃O₄ composite nanofibers all have clearly identifiable functional groups. The FT-

IR spectra of PVA revealed the characteristic broad band at 2900–3000 cm⁻¹ for the CH₂ group and the CH₃ group, respectively. Strong absorption bands between 400 and 700 cm⁻¹ can be seen in the magnetite powder's FTIR spectrum. These are the typical absorption peaks of the (Fe-O) vibrations that are related to Fe₃O₄ [27]. The stretching and torsional vibration modes of the magnetite's (Fe-O) bonds are attributed to the intense peaks at 427, 479, 507 and 627 cm⁻¹.

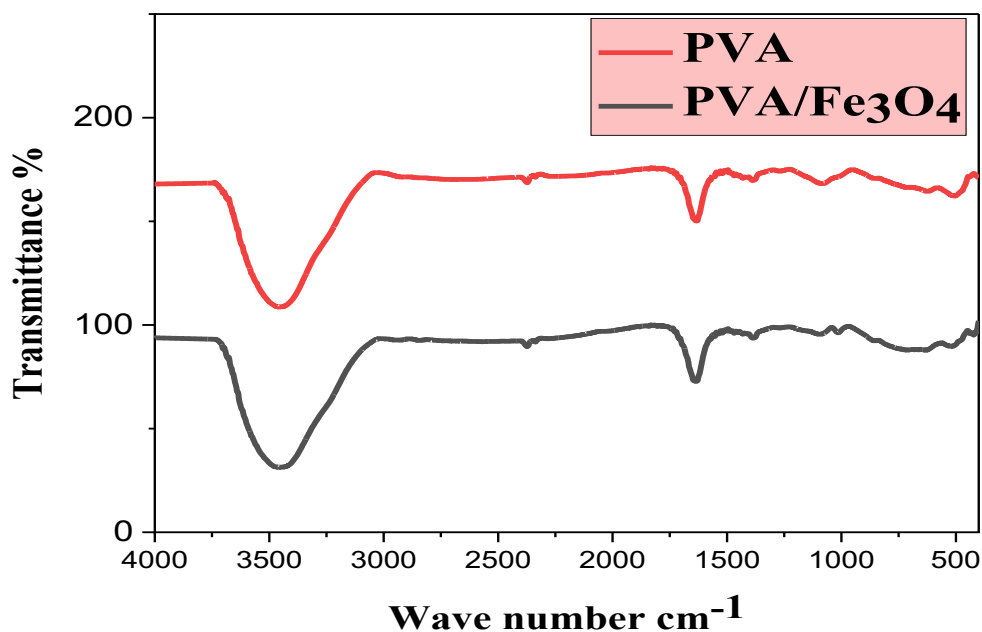


Fig. 3. FT-IR spectra of PVA nanofiber and PVA/Fe₃O₄ composite nanofiber.

3.3. Morphological and Structural Characterizations

The morphology of the surfaces of the manufactured magnetic iron oxide nanoparticles and nanofibers is shown in the images acquired with the SEM (**Figure. 4**). The nanofiber size was about 328 and 222 nm for PVA nanofiber and PVA/Fe₃O₄

composite nanofiber, respectively. The EDX spectrum dispersion results showed oxide and iron to be present in fiber (**Figure. 5**) the peak indicating the presence of carbon in the sample. The percentages of the elements carbon, iron and oxygen in the samples are 64.76, 0.68 and 34.56 % respectively.

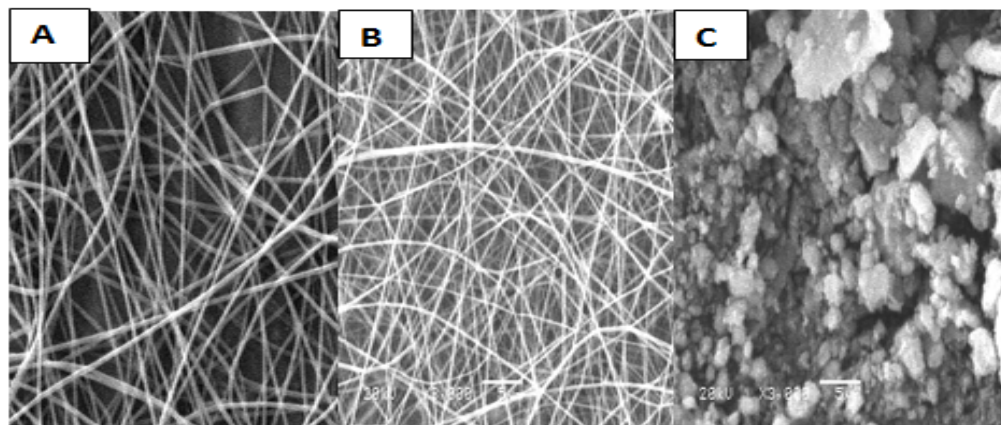


Fig. 4. SEM images of (A) PVA nanofiber, (B) PVA/Fe₃O₄ composite nanofiber, (C) magnetic iron oxide nanoparticles.

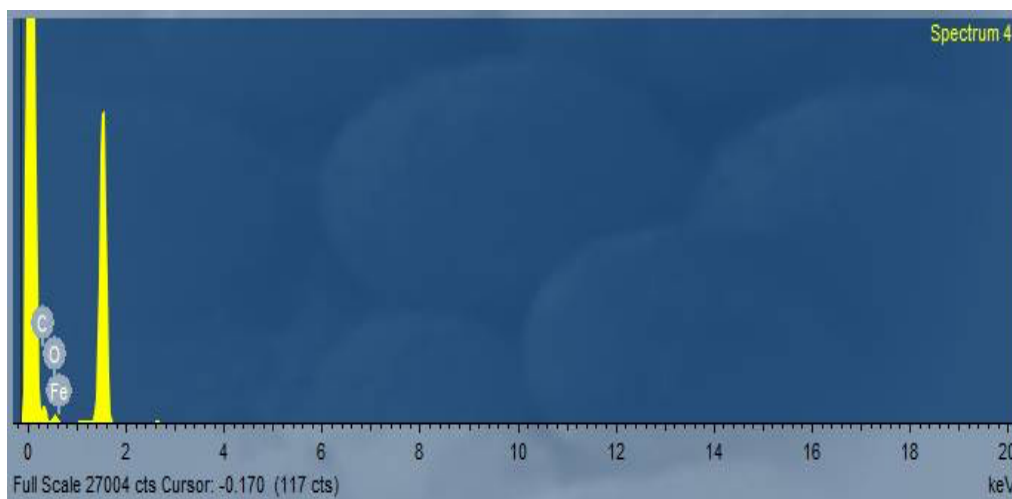


Fig. 5. EDX spectrum of PVA/Fe₃O₄ composite.

3.4 Electrochemical characterization

The electrode materials were electrochemically evaluated using cyclic voltammetry (CV). Cyclic voltammetry (CV) is one sort of electrochemical measurement that may be used to assess the specific capacitance of electrode materials. (**Figure. 6**) displays the cyclic voltammogram of PVA nanofiber and PVA/Fe₃O₄ composite nanofiber. The cyclic voltammogram of PVA exhibits a very low capacitance current with no redox peaks, as

illustrated in (**Figure. 6**). In addition, due to the inclusion of Fe₃O₄, cyclic voltammograms of PVA/Fe₃O₄ nanofiber (**Figure. 6**) show exceptional electrochemical efficiency and good capacitance characteristics. The negative current zone of the CV curve is produced by the cathodic reduction process, whereas the positive current zone is produced by the anodic oxidation process. The CV curve

demonstrates PVA nanofiber and Fe₃O₄ characteristics, which correspond to the pseudo-capacitance and double-layer capacitance of PVA/Fe₃O₄. The CV curves depart from the ideal rectangular form (as observed in perfect capacitors),

with some redox peaks in the negative and positive current areas, demonstrating that PVA/Fe₃O₄ is pseudocapacitive. This deviation from ideal capacitor performance is caused by a decrease in electrode and electrolyte contact [28]. PVA/Fe₃O₄ composite nanofiber has the largest specific capacitance (168 F/g) compared to PVA nanofiber (5.6F/g). This is

because of the presence of Fe₃O₄ which provides large surface area for charge accumulation; enhance the conductivity and distribution of ions in the PVA/Fe₃O₄ nanocomposite.

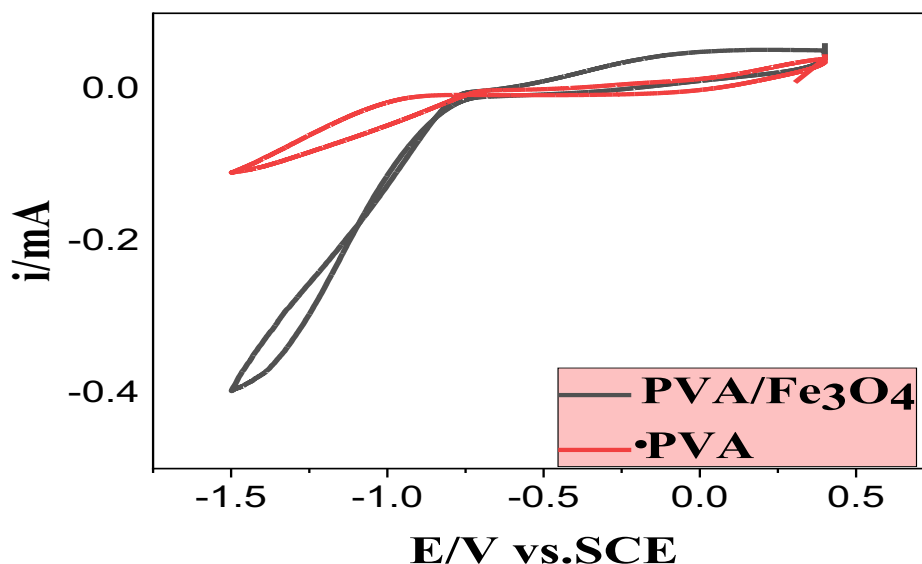


Fig. 6. cyclic voltammetry (CV) of PVA nanofiber and PVA/Fe₃O₄ composite nanofiber electrodes at a scan rate of 0.05mV/s.

4. Conclusion

PVA/Fe₃O₄ nanocomposite has been effectively produced utilizing integrative electrospinning processes. SEM images show the diameter of the PVA nanofibers and PVA/Fe₃O₄ nanocomposite. The presence of Fe₃O₄ nanoparticles onto PVA nanofibers was demonstrated by FTIR and EDX analyses. The nanoparticles Fe₃O₄ offers high electrical conductivity and surface area, which improves the electrochemical characteristics of the nanocomposite. In a potential range of 0.5V, the PVA/Fe₃O₄ nanocomposite demonstrated a significant specific capacitance (168 F/g) and outstanding electrochemical performance. As a result, metal oxides are very cost-effective possibilities for fabricating supercapacitor electrodes, albeit such options require various modifications (fabrication processes, electrolyte selection, etc.) to actually generate a novel electrode material in energy storage applications. These results demonstrated that PVA/Fe₃O₄ nanofiber could be suitable to use in supercapacitor applications.

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