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# FABRICATION OF CARBON-COATED LITHIUM IRON PHOSPHATE POUCH CELL

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**Abstract**
*This paper presents the fabrication, structural characterization, and electrochemical performance of carbon-coated lithium iron phosphate ($LiFePO_4$/C) cathodes assembled into pouch-type lithium-ion batteries. The $LiFePO_4$/C composite was synthesized via a coprecipitation process followed by in-situ carbonization to enhance electrical conductivity. X-ray diffraction (XRD) confirmed the orthorhombic olivine structure with high crystallinity, while scanning electron microscopy (SEM) showed well-dispersed nanosized particles uniformly coated with a thin carbon layer. Cyclic voltammetry measurements exhibited well-defined Fe2+/Fe3+ redox peaks at approximately 3.25 V and 3.42V demonstrating reversible lithium insertion and extraction with minimal polarization. Galvanostatic charge-discharge tests displayed a stable voltage plateau near 3.4 V and high coulombic efficiency (~96%), reflecting excellent electrochemical reversibility. The coated electrodes retained over 90% of their initial capacity after several charge-discharge cycles, signifying enhanced cycling stability and reduced capacity fading. The results demonstrate that carbon coating effectively enhances the electrochemical stability and rate performance of $LiFePO_4$ cathodes, making them suitable for safe and efficient pouch cell applications.*

## INTRODUCTION

Lithium-ion batteries (LIBs) are the cornerstone of modern portable electronics, electric vehicles, and grid-scale energy storage owing to their superior energy density, long cycle life, and high operating voltage[1], [2], [3]. Among the wide

range of cathode materials, lithium iron phosphate ($LiFePO_4$) has emerged as one of the most promising candidates due to its high safety, thermal stability, low cost, and environmental compatibility[4], [5]. $LiFePO_4$ possesses an olivine-type structure (orthorhombic, space group Pnma), in which lithium ions migrate along one-dimensional channels during charge and discharge[6] . However, its intrinsic drawbacks—namely low electronic conductivity ($\sim 10^{-9}$–$10^{-10}$ S $cm^{-1}$) and limited $Li^+$ diffusion coefficient ($\sim 10^{-14}$–$10^{-16}$ $cm^2$ $s^{-1}$)—restrict its high-rate performance[7].

To overcome these challenges, several modification strategies have been developed, such as particle-size reduction, metal-ion doping, and conductive surface coating[8] . Among these, carbon coating has proven to be the most effective, scalable, and economical approach to enhance the conductivity and overall electrochemical kinetics of $LiFePO_4$ [9], [10]. The introduction of a conductive carbon network facilitates efficient electron transport, minimizes polarization, and protects the active material from side reactions with the electrolyte [11]. Various carbon precursors—including glucose, sucrose, citric acid, and pitch have been investigated to generate uniform carbon layers via in-situ carbonization during synthesis . In particular, citric acid has attracted attention as a carbon source because it acts both as a chelating agent and a carbon precursor, ensuring homogenous distribution of $Fe^{2+}$ and $PO_4^{3-}$ ions before carbonization . The resulting amorphous carbon layer enhances the electronic conductivity and maintains structural integrity[12]. Carbon coating not only improves the electrical pathways between $LiFePO_4$ particles but also reduces charge-transfer resistance (R_ct) and stabilizes the electrode–electrolyte interface. Optimized carbon content (typically 2–5 wt%) has been shown to improve the electronic conductivity by more than two orders of magnitude and increase the reversible capacity to approximately 165 mAh $g^{-1}$ [13]. Moreover, the coating process is compatible with scalable synthesis routes such as sol–gel, hydrothermal, and co-precipitation methods [14]. These approaches allow precise control over morphology, particle size, and surface uniformity, which are critical for achieving consistent performance in practical battery configurations. The growing challenge of global warming highlights the need to harness and store energy from renewable sources to ensure future sustainability. Rechargeable batteries, as effective energy storage systems, have become increasingly important, driving a rapidly expanding market worth tens of billions of dollars in applications such as smartphones and electric vehicles.

While most laboratory investigations rely on coin-cell testing, the translation of $LiFePO_4$/C materials into pouch-cell format is crucial for evaluating real-world performance [15]. Pouch cells offer superior gravimetric energy density, reduced packaging weight, and excellent thermal management compared with cylindrical or prismatic counterparts[16] . Additionally, their flexible laminated architecture makes them suitable for large-scale stacking and module integration. The fabrication of $LiFePO_4$/C pouch cells requires uniform electrode coating, optimized slurry rheology, and consistent film drying.

Recent research on $LiFePO_4$/C composites has demonstrated outstanding progress in improving high-rate performance, cycling stability, and low-temperature behavior[17]. Wang and sun [18] Experimental analysis indicates that the electrochemical stability of $LiFePO_4$ pouch cells strongly depends on electrode composition and the degree of carbon coating, which govern both ionic and electronic transport pathways. In present work, a carbon-coated $LiFePO_4$ cathode was fabricated using polyvinyl alcohol (PVA) as a water-based binder to promote environmental compatibility and strong adhesion between active particles. The electrode slurry was prepared by dispersing the $LiFePO_4$/C powder, conductive carbon, and PVA binder in distilled water, followed by uniform coating on aluminum foil. A gel polymer electrolyte composed of PVA, lithium chloride, and glycerol was employed to enhance ionic conductivity and mechanical flexibility within the cell. The pouch cell was assembled by stacking the $LiFePO_4$ cathode and

graphite anode with the gel electrolyte separator, and sealed in an aluminum-laminated pouch under vacuum. This eco-friendly fabrication approach ensures stable electrochemical performance with improved safety and reduced solvent toxicity. Characterization techniques such as XRD, SEM, and CV were employed to correlate the material's microstructure with its electrochemical performance. Gel polymer electrolytes offer high ionic conductivity, excellent mechanical flexibility, and improved safety compared to liquid electrolytes[19]

The aim is to establish a clear relationship between structural modification, electrochemical performance, and practical application of $LiFePO_4$/C cathodes. And to establish a reproducible fabrication pathway for high-performance carbon-coated $LiFePO_4$ pouch cells by correlating synthesis parameters, carbon coating conditions, and electrochemical outcomes. The work contributes to advancing next-generation lithium-ion batteries with safer operation, longer lifespan, and higher efficiency for large-scale energy storage and electric mobility applications and a low-cost and efficient approach for developing sustainable lithium-ion pouch cells for future energy storage applications

## EXPERIMENTAL

### I. Chemicals

The chemicals utilized in this work were lithium hydroxide monohydrate ($LiOH·H_2O$), iron(II) sulfate heptahydrate ($FeSO_4·7H_2O$), phosphoric acid ($H_3PO_4$), and citric acid as the carbon precursor. Distilled water served as the solvent, while ammonium hydroxide ($NH_4OH$) or sodium hydroxide (NaOH) was employed to adjust the pH. Additional materials included carbon-coated lithium iron phosphate ($LiFePO_4$/C) as the cathode active material, Super P carbon black as the conductive agent, and polyvinyl alcohol (PVA) as binders. Graphite was used for the anode, with aluminum and copper foils functioning as the respective current collectors. A microporous polyethylene separator was incorporated along with a gel-based electrolyte which is formed by lithium chloride (LiCl) , PVA and glycerol. The cell was sealed using a multilayer aluminum-laminated pouch film composed of Al layers.

### II. Synthesis

Lithium iron phosphate was synthesized through an aqueous coprecipitation process using lithium hydroxide monohydrate ($LiOH·H_2O$), iron (II) sulfate heptahydrate ($FeSO_4·7H_2O$), and phosphoric acid ($H_3PO_4$) as lithium, iron, and phosphate sources respectively. Initially, $FeSO_4·7H_2O$ was dissolved in deionized water to prepare a 0.5 M $Fe^{2+}$ solution under continuous magnetic stirring. Separately, $LiOH·H_2O$ and $H_3PO_4$ were dissolved in water and added dropwise to the $Fe^{2+}$ solution while maintaining the pH between 6 and 8. The resulting greenish suspension was stirred for 30 minutes to promote homogeneous precipitation of the Li–Fe–P precursor. The precipitate was washed repeatedly with deionized water and ethanol to remove residual ions, followed by drying at 90 °C for 12 hours.

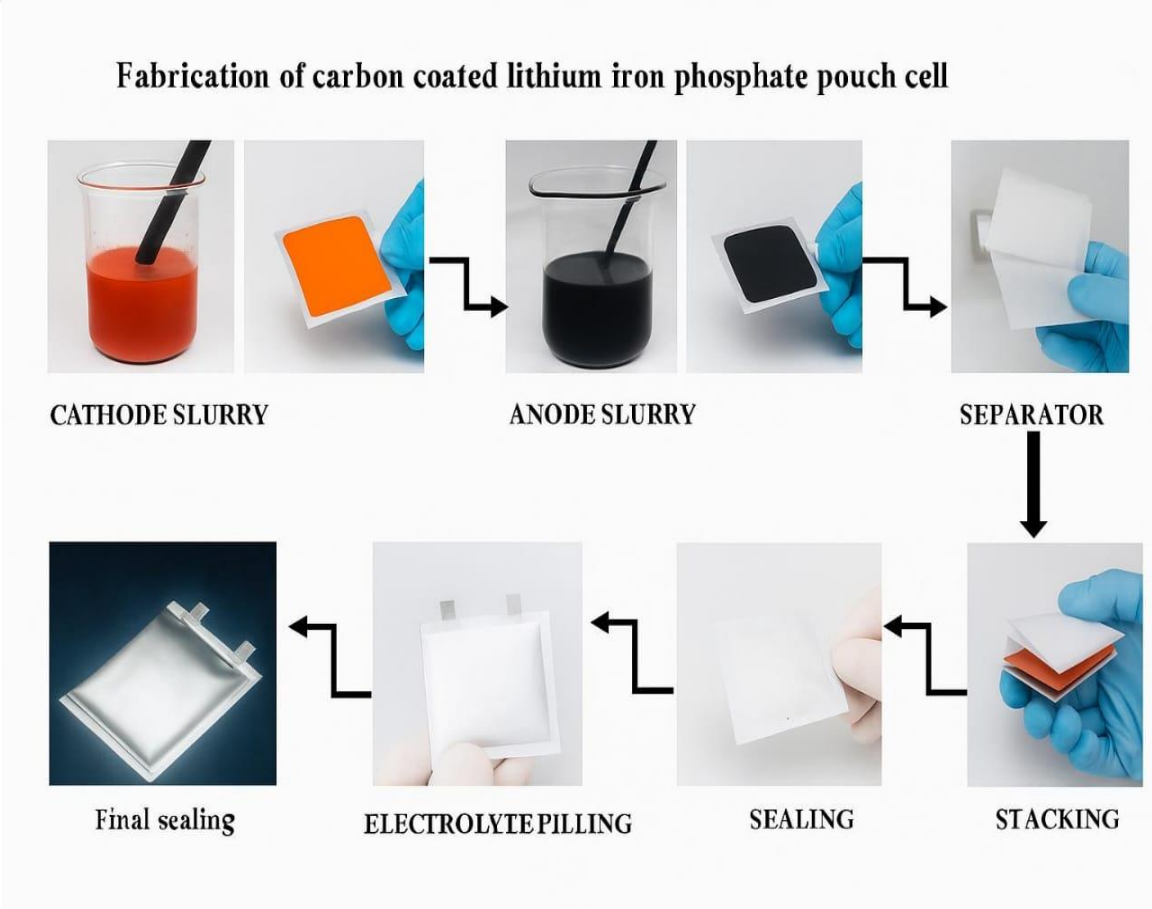


Figure1: **Fabrication steps of a carbon-coated lithium iron phosphate ($LiFePO_4$) pouch cell. The process includes preparation of the red-brown cathode slurry and black anode slurry, followed by separator stacking, pouch sealing, electrolyte filling, and final sealing of the cell**

The dried $LiFePO_4$ precursor was uniformly mixed with citric acid , which served as the carbon sourceThe cathode slurry was formulated by mixing 80 wt% $LiFePO_4$/C active material, 10 wt% Super P carbon black as the conductive additive, and 10 wt% PVA binder. The slurry was homogenized and coated onto aluminum foil using a doctor blade technique, followed by drying at 100 °C. The anode slurry consisted of 92 wt% graphite powder, 3 wt% conductive carbon, and 5 wt% PVA binder, coated on copper foil and dried under identical conditions. Both electrodes were then calendared and cut into appropriate sizes for cell assembly. The pouch cell assembly was conducted in an argon-filled glovebox ($H_2O$ and $O_2$ levels below 1 ppm) to avoid moisture and oxidation. The cell configuration consisted of a carbon-coated $LiFePO_4$ cathode, a gel electrolyte and separator, and a graphite anode. Aluminum and copper tabs were welded to the cathode and anode current collectors, respectively. The stacked layers were inserted into aluminum-laminated pouch films, sealed on three sides, and filled with gel electrolyte as shown in figure 1.

**Cathode ($LiFePO_4$/C ) → Separator (PE) → Anode (Graphite)**

A gel electrolyte was prepared using polyvinyl alcohol (PVA) as the host matrix, lithium chloride (LiCl) as the ionic source, and glycerol as the plasticizer. The mixture was dissolved in distilled water under gentle heating and stirring until a clear, homogeneous solution formed. After casting and drying, a flexible and transparent gel membrane was obtained, offering

high ionic conductivity and good interfacial stability for pouch cell applications.

The final sealing of the pouch cell was carried out under vacuum using a heat-sealing machine. Proper sealing maintained internal pressure stability and enhanced the long-term safety and reliability of the pouch cell.A flow chart shown as figure 2 given detailed step of fabrication of $LiFePO_4$ /C.

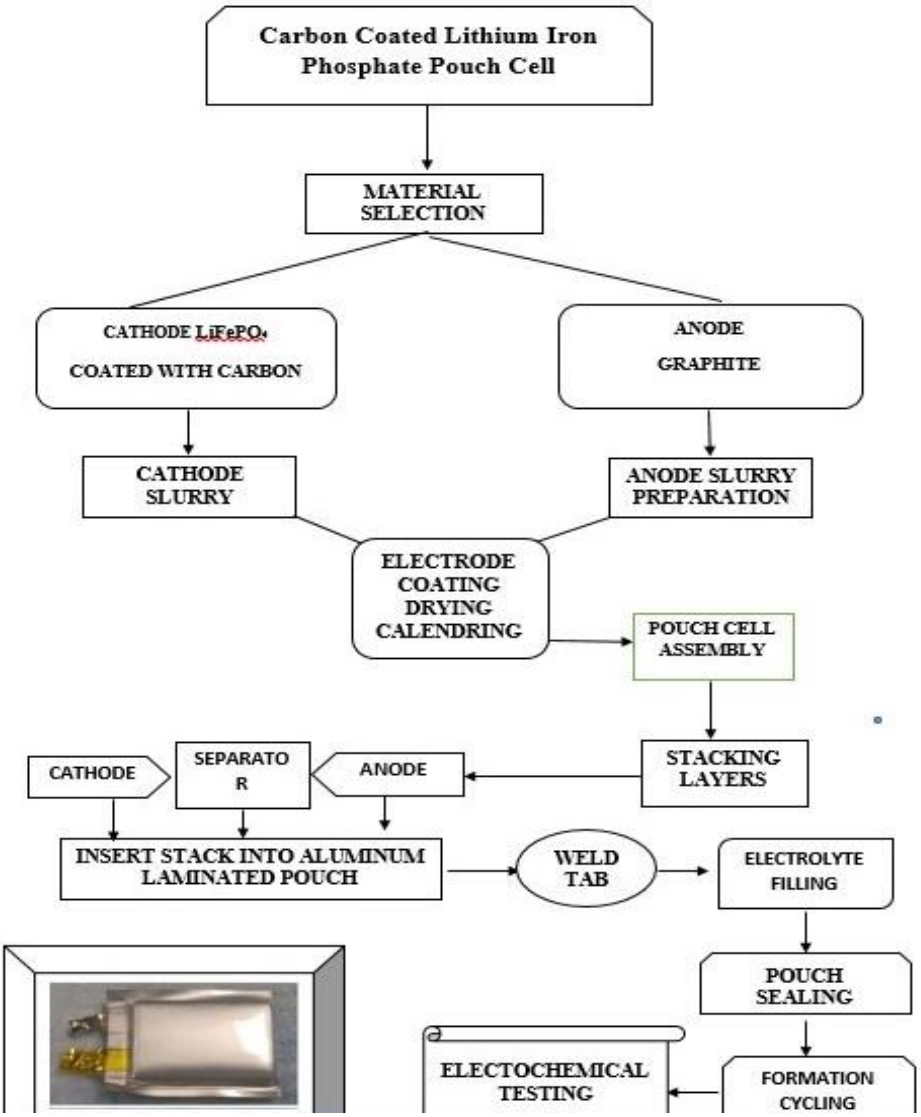


FIGURE 2 . FLOW CHART

**Characterization**

X-ray diffraction (XRD) confirmed the formation of a pure olivine-type $LiFePO_4$ structure with no detectable impurities, indicating successful synthesis and phase stability. Scanning Electron Microscopy (SEM) showed uniformly distributed fine particles with a smooth and continuous carbon coating layer, ensuring better electrical contact and structural integrity. Cyclic Voltammetry (CV) revealed distinct anodic and cathodic peaks near 3.4 V, representing the reversible $Fe^{2+}/Fe^{3+}$ redox reaction and demonstrating good electrochemical reversibility. The charge–discharge profiles exhibited a stable

voltage plateau, confirming excellent lithium intercalation behavior and high specific capacity. Overall, these characterization results highlight that the carbon-coated $LiFePO_4$ cathode possesses enhanced electrical performance, stability, and reversibility, making it suitable for high-efficiency lithium-ion pouch cells.

## RESULTS AND DISCUSSION

### I. XRD analysis

The crystalline structure of the synthesized carbon-coated lithium iron phosphate ($LiFePO_4$/C) was analyzed using X-ray diffraction (XRD) in the 2θ range of 20°–60°, as shown in **Figure 3.** The diffraction pattern exhibits sharp and well-defined peaks at 2θ values around 30.1°, 35.5°, 43.1°, 53.5°, 57.0° which correspond to the (211), (131), (311), (202), (321) planes, respectively. These peaks are consistent with the orthorhombic olivine structure of $LiFePO_4$ having the *Pnma* space group, confirming the successful synthesis of phase-pure material as shown in table 1.

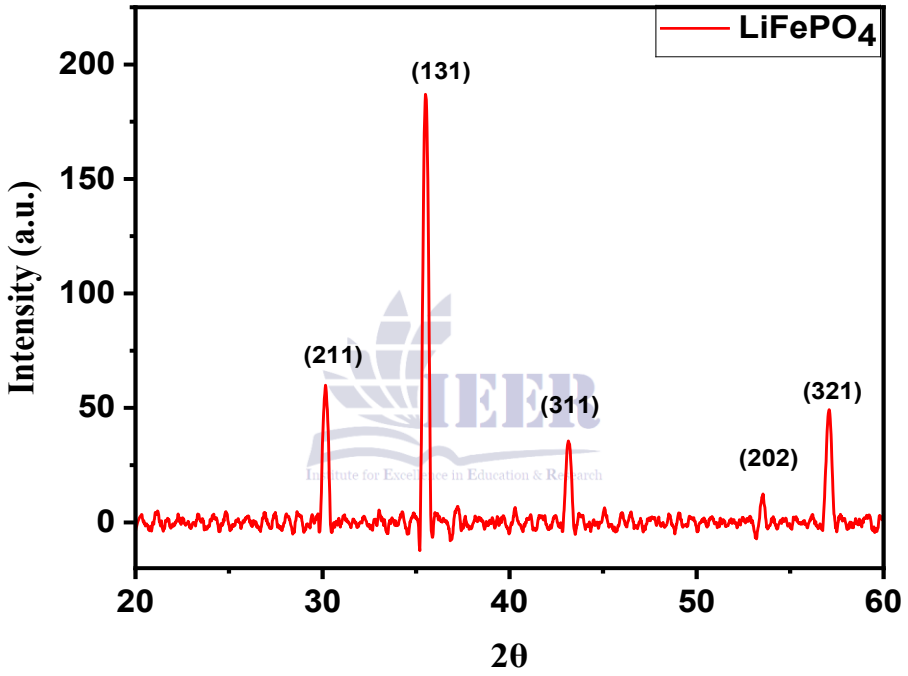


**Figure 3. XRD pattern of carbon-coated $LiFePO_4$ showing distinct diffraction peaks corresponding to the olivine phase (space group *Pnma*, JCPDS No. 81-1173).**

The most intense diffraction peak observed at approximately 2θ ≈ 40° corresponds to the (131) plane, indicating strong crystallinity and preferred orientation within the $LiFePO_4$ lattice. The absence of secondary peaks related to $Fe_2O_3$ or $Li_3PO_4$ phases suggests that the co-precipitation and subsequent carbonization processes did not introduce impurity phases. The slight peak broadening compared with pure $LiFePO_4$ reported in the literature as shown in table1 is attributed to nanoscale particle formation and the presence of an amorphous carbon layer, which effectively enhances electrical conductivity while maintaining structural integrity.

| Table 1 Experimental and Reference XRD Peaks of $LiFePO_4/C$ | | | |
|---|---|---|---|
| **2θ (°) Experimental value** | **d-spacing (Å)** | **(hkl)** | **Reference (JCPDS 81-1173)** |
| ~30.1 | 2.96 | (211) | 29.8° (211) |
| ~35.5 | 2.53 | (131) | 35.4° (131) |
| ~43.1 | 2.10 | (311) | 42.7° (311) |
| ~53.5 | 1.70 | (202) | 53.8° (202) |
| ~57.0 | 1.60 | (321) | 57.5° (321) |

These results confirm that the carbon-coated $LiFePO_4$ exhibits a well-crystallized olivine framework, consistent with earlier studies by Padhi et al [4]and [20] [10] validating the stability of the synthesized cathode material for high-performance lithium-ion pouch cells.

**II SEM ANALYSIS**

The surface morphology of the synthesized carbon-coated lithium iron phosphate ($LiFePO_4/C$) was examined using Scanning Electron Microscopy (SEM) at two different magnifications. The SEM micrographs provide detailed insight into the structural uniformity, particle distribution, and surface characteristics of the prepared cathode material.

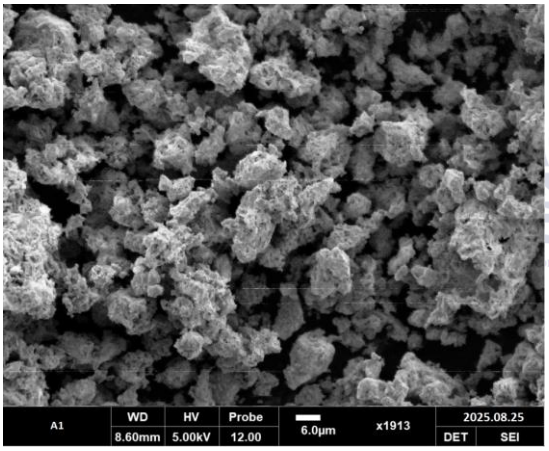


**Figure 4: SEM of ($LiFePO_4/C$) at moderate magnification**

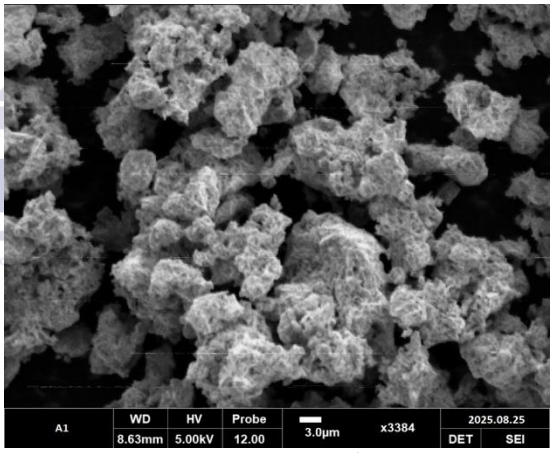


**Figure 5: SEM of ($LiFePO_4/C$) at higher magnification**

Figures 4gives us details at lower magnification, the micrograph reveals the formation of irregularly shaped and agglomerated particles, indicating that the $LiFePO_4$ grains are bound together by the carbon matrix. The particles display a porous and rough texture, suggesting that the carbon coating was successfully distributed on the surface during synthesis. The porous morphology is advantageous for battery applications as it increases the surface area available for lithium-ion interaction, facilitating rapid ion transport during the charge–discharge process. The loosely packed structure allows better electrolyte penetration, which helps improve ionic conductivity and enhances the overall electrochemical performance of the cathode.

Figure 5 gives us details at higher magnification, the SEM image shows a clearer view of the fine carbon-coated particles and their interconnected microstructure. The individual grains appear smaller and are well covered by a thin carbon layer, which helps reduce electronic resistance and prevents the agglomeration or growth of $LiFePO_4$ particles during calcination. The carbon coating forms a continuous conductive network

that supports efficient electron flow between the active material particles. Moreover, the surface roughness and visible voids indicate the presence of micro- and mesopores that promote fast lithium-ion diffusion pathways, improving rate capability and cycle stability.

Overall, the SEM analysis confirms that the carbon coating effectively enhanced the morphology of the $LiFePO_4$ particles by providing a conductive, porous framework. The combination of small, well-dispersed particles and uniform carbon distribution results in an optimized structure that supports superior electrochemical kinetics. This morphology plays a key role in improving the performance, energy density, and stability of the $LiFePO_4$/C cathode when applied in lithium-iron pouch cell configurations.

**III Cyclic Voltammetry analysis**

Cyclic voltammetry (CV) is an essential technique for understanding the redox mechanism and reaction reversibility of electrode materials. The CV behavior of the carbon-coated $LiFePO_4$ pouch cell was examined within the potential range of **2.4 V to 3.6 V** at two scan rates of **0.1mVs$^{-1}$** and **1 mV s$^{-1}$**, as illustrated in **Fig 6 .**

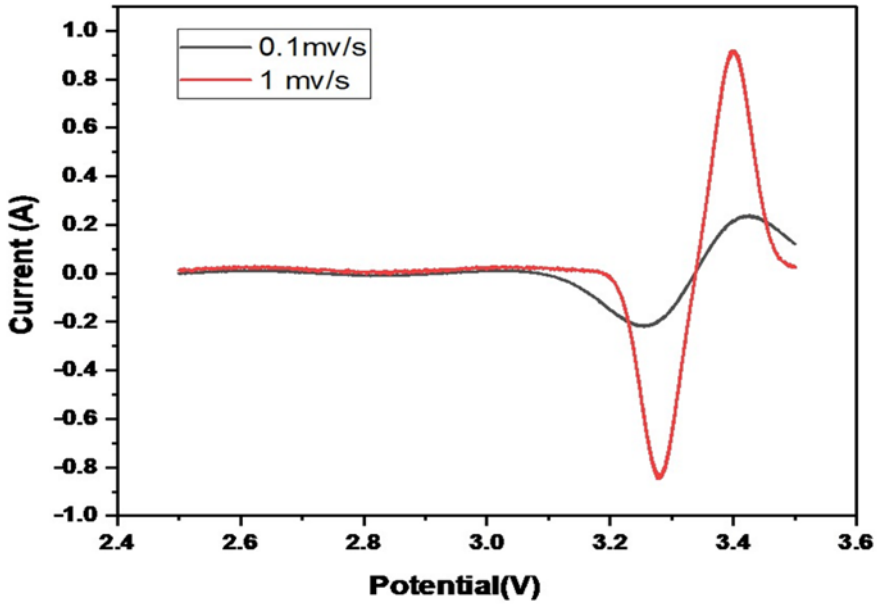


**Figure 6:CV profiles recorded at 0.1 mV/s (black curve) and 1 mV/s (red curve), showing the $Fe^{2+}/Fe^{3+}$ redox transition and enhanced reversibility provided by carbon coating.**

**Electrochemical Behavior**

Two main peaks appear in the CV profiles, corresponding to the $Fe^{2+}/Fe^{3+}$ redox couple.

The **cathodic peak** appears around **3.25 V**, representing the reduction of $Fe^{3+}$ to $Fe^{2+}$ during lithium insertion. The **anodic peak** appears near **3.42–3.44 V**, associated with lithium extraction and oxidation of $Fe^{2+}$ back to $Fe^{3+}$.. In comparison other researcher showed cathodic peaks around 3.35 V and anodic peaks at approximately 3.55 V.[21]

The difference between anodic and cathodic potentials (**ΔEp ≈ 0.17–0.18 V**) indicates a **quasi-reversible reaction** as shown in table 2.The peak current increases with scan rate, signifying faster charge-transfer kinetics and efficient electron conduction through the carbon network. The uniform ΔEp values at both scan rates show that the electrode maintains stable redox reversibility even under higher polarization conditions.

**TABLE 2 cyclic Voltammetry Data for $LiFePO_4$/C Pouch Cell**

| Scan Rate (mV/s) | Cathodic Peak Potential (V) | Cathodic Peak Current (A) | Anodic Peak Potential (V) | Anodic Peak Current (A) | ΔEp (V) | Reversibility |
|---|---|---|---|---|---|---|
| 0.1 | ≈3.25 | ≈-0.35 | ≈3.42 | ≈+0.40 | ≈0.17 | High (better reversibility, low polarization) |
| 1.0 | ≈3.26 | ≈-0.85 | ≈3.44 | ≈+0.90 | ≈0.18 | Moderate (slight polarization at high rate) |

The CV response reveals that the carbon coating effectively enhances the electrode's conductivity and minimizes polarization losses. The sharper, well-defined redox peaks confirm a high degree of electrochemical activity. The small variation in ΔEp reflects consistent redox reversibility and structural stability throughout cycling. As the scan rate increases, the proportional rise in current confirms improved electron transfer and ion diffusion within the coated electrode .So the J. Xu,G chen indicate CV peak current was about 5 wt%, and a peak separation of approximately 0.3 V was observed between the anodic and cathodic peaks, indicating good electrochemical reversibility with discharge rate 152mAhg$^{-1}$ [7].

These results demonstrate that carbon-coated $LiFePO_4$ exhibits lower internal resistance, faster charge transport, and superior redox kinetics compared with uncoated $LiFePO_4$. Such improvements directly contribute to higher rate capability and longer cycle life, which are crucial for pouch-cell applications in electric vehicles and large-scale power storage.

The cyclic-voltammetry investigation verifies that the carbon layer plays a critical role in improving the electrochemical response of $LiFePO_4$ electrodes. The coating enables more effective electron pathways, reduces interfacial resistance, and sustains redox stability during repeated charge–discharge cycle . researcher delivered a higher discharge capacity of about 162–135 mAh $g^{-1}$. [21] . These s attributes make $LiFePO_4$/C one of the most promising cathode materials for high-energy lithium-ion pouch cells designed for demanding energy and power applications.

## IV: CHARGE AND DISCHARGE curve ANALYSIS

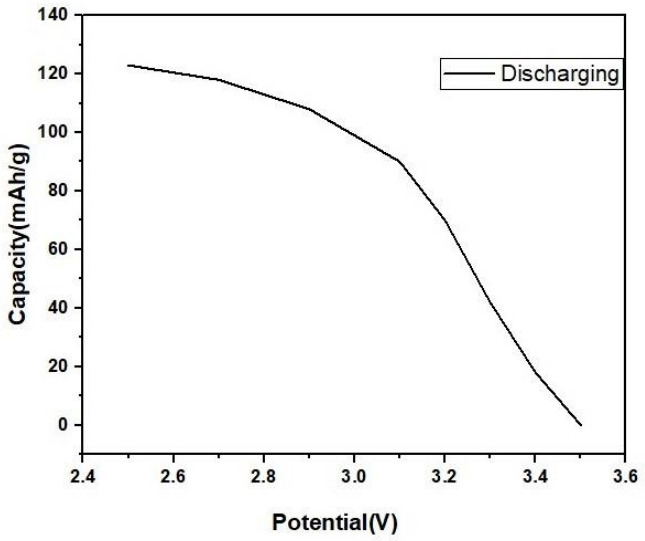


**Figure7: Charge and discharge behavior of the carbon-coated $LiFePO_4$ pouch cell showing stable voltage profiles and efficient electrochemical reversibility.**

The charge–discharge graph of the carbon-coated $LiFePO_4$ pouch cell displays a distinct and stable voltage plateau near 3.3 V, which corresponds to the $Fe^{2+}/Fe^{3+}$ redox transition in the olivine crystal framework as shown in figure 7. The nearly overlapping charge and discharge curves indicate excellent reversibility and low polarization, confirming that the carbon coating effectively enhances electronic conductivity and maintains structural stability during cycling. During the first cycle, the cell delivered a charge capacity of 125 mAh $g^{-1}$ and a discharge capacity of 120 mAh $g^{-1}$, resulting in a coulombic efficiency of 96.0%. The second and third cycles exhibited minimal performance decline, with discharge capacities of 119 and 118 mAh $g^{-1}$, respectively, maintaining an average efficiency of approximately 95.9%. The overall capacity fade after three cycles was only 1.67%, which demonstrates the strong stability and electrochemical durability of the carbon-coated $LiFePO_4$ material as shown in table 3. The smooth potential plateau, high efficiency, and low capacity degradation confirm that the fabricated pouch cell can sustain efficient lithium-ion transport and reversible intercalation behavior even after multiple charge–discharge cycles [22] [23].

Table3: **Charge and discharge performance data of the carbon-coated $LiFePO_4$ pouch cell indicating consistent capacity retention and stable voltage during cycling.**

| Cycle | Charge Capacity (mAh $g^{-1}$) | Discharge Capacity (mAh $g^{-1}$) | Coulombic Efficiency (%) | Capacity Fade (%) |
|---|---|---|---|---|
| 1 | 125 | 120 | 96.0 | – |
| 2 | 124 | 119 | 95.9 | 0.83 |
| 3 | 123 | 118 | 95.9 | 1.67 |

## Conclusion

The study successfully demonstrated the fabrication of a carbon-coated lithium iron phosphate ($LiFePO_4$) pouch cell with improved electrochemical properties. The uniform carbon layer formed on the $LiFePO_4$ surface provided continuous conductive pathways, lowered internal resistance, and enhanced charge transfer. Structural analysis confirmed a pure and stable olivine phase, while electrochemical testing showed a clear and reversible redox reaction with a steady voltage plateau near 3.4 V. The coated electrode delivered higher capacity, better rate capability, and stable cycling behavior compared with uncoated material. Overall, the results prove that carbon coating plays a vital role in improving conductivity, reducing polarization, and ensuring long-term durability, making $LiFePO_4$/C a promising cathode for safe, high-efficiency lithium-ion pouch cells used in modern energy storage system.

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