International Journal of Chemical Studies 2024; 12(1): 51-59

International Journal of Chemical Studies

P-ISSN: 2349-8528
E-ISSN: 2321-4902
www.chemijournal.com
IJCS 2024; 12(1): 51-59
© 2024 IJCS
Received: 06-11-2023
Accepted: 11-12-2023

Synthesis and characterization of polypyrrole composites: Optimization strategies for tailored material qualities and enhanced applications

Jyoti, Kusum Lata and Pallavi Bhardwaj

Jyoti
Department of chemistry, Baba Mastnath University, Rohtak, Haryana, India

Kusum Lata
Department of chemistry, Baba Mastnath University, Rohtak, Haryana, India

Pallavi Bhardwaj
Department of chemistry, Baba Mastnath University, Rohtak, Haryana, India

Corresponding Author:
Pallavi Bhardwaj
Department of chemistry, Baba Mastnath University, Rohtak, Haryana, India

DOI: https://doi.org/10.22271/chemi.2024.v12.i1a.12398

Abstract

This study aims to investigate the synthesis and characterization of polypyrrole (PPy) composites using various reactants, with a focus on optimizing synthesis conditions to achieve desired material qualities. The objective is to explore the influence of temperature, reaction time, concentrations, and ratios on the structural and electrical properties of the produced composites. The synthesis process involves the oxidative polymerization of pyrrole employing different metal salts ($FeCl_3$ and Iron (III) Tosylate) and a polymeric dopant (PSS). Material analysis is conducted using X-ray Diffraction (XRD) and UV-Visible Spectroscopy techniques. XRD patterns reveal distinct crystal planes and orientations in multiple composites, providing valuable insights into their structural organization. UV-Visible absorption spectra exhibit electronic transitions at varying wavelengths, elucidating the optical characteristics of the materials. Precise control over synthesis conditions significantly influences the shape, crystallinity, and electronic properties of PPy composites. Systematic optimization leads to tailored properties, enhancing their potential applications in sensors, actuators, and energy storage systems. This research contributes essential knowledge for the systematic advancement and improvement of PPy composites, facilitating progress in materials science and technology. In particular, the investigation of the PPy-La_2O_3 composite presents novel insights into its structural and optical properties, expanding the understanding of this material system. Keywords- Polypyrrole Composites, Synthesis Optimization, Material Characterization, X-ray Diffraction and Electronic Transitions.

Keywords: X-ray Diffraction, Tosylate, pyrrole, tailored material

Introduction

The exploration of conducting polymers has emerged as a fascinating field of research, offering a myriad of possibilities for applications in various technological domains. Among these, polypyrrole stands out as a particularly promising candidate due to its unique electrical, optical, and mechanical properties. This study delves into the preparation, characterization, and application of conducting polypyrrole and its composites, aiming to unravel the potential it holds for diverse practical uses. The synthesis of polypyrrole involves the electrochemical or chemical oxidation of pyrrole monomers, resulting in a highly conductive and versatile polymer (Hao *et al*., 2022) [10]. One of the key focuses of this research is the meticulous preparation of polypyrrole and its composites, ensuring the fine-tuning of their properties to meet specific application requirements. The synthesis process involves the manipulation of reaction parameters, such as monomer concentration, reaction time, and temperature, to achieve the desired structure and performance. Characterization plays a pivotal role in understanding the fundamental properties and structural nuances of the synthesized polypyrrole and its composites. Advanced techniques such as spectroscopy, microscopy, and thermal analysis are employed to scrutinize the molecular and morphological aspects of the materials. This comprehensive characterization enables researchers to gain insights into the electronic structure, conductivity, and thermal stability, which are critical factors influencing the materials' applicability in different contexts (Chemistry, 2023; Ono, 2023; Saliba & Barnes, 2022; Sonika *et al*., 2022) [4, 16, 17, 19]. The versatility of polypyrrole is further enhanced through the incorporation of various composites. Combinations with nanoparticles, carbon-based materials, or other polymers contribute to synergistic effects, offering improved mechanical strength, enhanced conductivity, and expanded functionality (Díaz-Muñoz *et al*., 2022; Kamalov *et al*., 2022; Krishna Prasad *et al*., 2022; Nanoparticles *et al*., 2023) [6, 13, 14, 15]. The study systematically investigates the impact of different composite formulations on the overall performance of the materials, elucidating the mechanisms underlying their enhanced properties. Application-oriented research forms a significant aspect of this study, as the synthesized polypyrrole and composites are evaluated for their utility in diverse fields. The applications span a wide spectrum, ranging from sensors and actuators to energy storage devices and electronic components. The exceptional conductivity of polypyrrole, coupled with the tailored properties of its composites, positions these materials as promising candidates for next-generation technologies. This investigation into conducting polypyrrole and its composites is poised to contribute significantly to the expanding realm of advanced materials (Guan *et al*., 2022; Hao *et al*., 2022; S. Wang *et al*., 2021; Yi *et al*., 2022; Zhou, 2022) [9, 10, 19, 23, 25]. The precision in preparation, thorough characterization, and exploration of diverse applications underscore the multifaceted nature of these materials. As researchers delve deeper into the intricacies of polypyrrole, the potential for ground breaking innovations in electronics, sensors, and energy storage becomes increasingly evident, setting the stage for a new era in material science and technology.

Research Methodology

The methodology focuses on selecting specific materials, highlighting the importance of metal salts like Ferric Chloride and Iron (III) Tosylate, together with polymeric dopants such as Poly(styrene sulfonic acid) (PSS). The synthesis protocol emphasizes methodologies, parameter optimization, and systematic optimization to customize attributes for specific applications. Characterization techniques like as FTIR, SEM, and TEM are used to evaluate the structure and morphology. Adjusting settings to optimize characteristics guarantees that materials will full fill particular requirements. Application studies thoroughly assess the practical usefulness in real world scenarios, providing insights for improving materials for various uses.

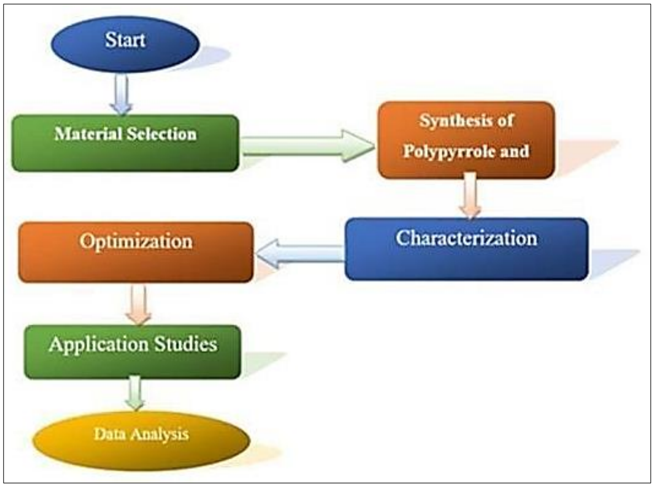

Fig1: Proposed Flowchart

Material Selection

In the synthesis of polypyrrole (PPy) and its composites, the choice of starting materials plays a pivotal role in determining the material's properties and applications. Among the metal salts, Ferric Chloride ($FeCl_3$) stands out as a versatile oxidizing agent and dopant utilized in the oxidative polymerization of pyrrole. Its efficacy lies in its ability to facilitate the formation of a conductive and stable PPy structure. Another noteworthy metal salt is Iron (III) Tosylate, recognized for its effectiveness as a dopant, contributing to the enhancement of PPy's conductivity, ultimately yielding materials with high electrical performance (Tu *et al*., 2021; J. Y. Wang *et al*., 2020; Yussuf *et al*., 2018) [19, 1, 24].

Polymeric dopants, such as Poly (styrene sulfonic acid) (PSS), offer a valuable avenue for improving solubility and conductivity in PPy. PSS's presence during polymerization enhances the material's electro active nature and promotes better process ability.

Preparation of Polypyrrole

In order to synthesize Poly (pyrrole) (PPy), the pyrrole monomer is dissolved in an appropriate solvent, often an organic solvent such as dichloromethane or acetonitrile. Next, an oxidizing agent is slowly introduced into the solution while continuously agitating it. Typical oxidizing agents include ferric chloride, ammonium persulfate, or iodine. This triggers the process of polymerization, resulting in the creation of PPy. The reaction occurs through oxidative polymerization, in which pyrrole monomers undergo oxidative coupling to create a polymer chain. The reaction can be expressed by the following equation:

$$\text{Pyrrole monomer} + \text{Oxidizing Agent} \rightarrow \text{Ppy} \qquad (1)$$

Continue stirring until the solution becomes viscous and dark-colored, indicating polymerization completion. Finally, the PPy product is isolated and washed for further characterization.

Preparation of Metal Oxide

The thermal breakdown of metal salts is a method that can be utilized to produce metal oxides. In the case of copper (II) nitrate Cu $(NO_3)_2$, for example, the creation of copper (II) oxide CuO and oxygen gas O_2 is the outcome of heating the precursor:

$$2Cu\,(NO_3)_2 \rightarrow 2CuO + 4NO_2 + O_2 \qquad (2)$$

This process involves breaking down the metal nitrate into metal oxide and gaseous by products upon heating. The resulting metal oxide can be further processed and utilized in various applications, such as catalysis, ceramics, and electronics.

Preparation of PPy-Metal Oxide

In situ polymerization processes can be used to create composites of poly (pyrrole) and metal oxides. In the manufacture of a composite material consisting of polypyrrole (PPy) and iron oxide (Fe_2O_3), iron salts are introduced into the reaction mixture during the process of oxidative polymerization of pyrrole. The polymerization reaction is initiated by an appropriate oxidizing agent such as ammonium persulfate, which leads to the simultaneous synthesis of PPy and the encapsulating of iron oxide nanoparticles within the polymer matrix:

Pyrrole + Fe (II) salt + Fe (III) salt + Oxidizing agent → PPy-Metal Oxide Composite (3)

This approach yields materials with synergistic properties suitable for applications in sensors, actuators, and energy storage devices.

Preparation of Lanthanum Oxide (La_2O_3) Nanoparticles: Chemical Equation

$$La\,(NO_3)_3 + H_2O \rightarrow La\,(OH)_3 + HNO_3 \qquad (4)$$

Explanation: This reaction represents the conversion of lanthanum nitrate [La $(NO_3)_3$] to lanthanum hydroxide [La $(OH)_3$] through a process called hydrolysis. Water (H_2O) is involved in the reaction, and nitric acid (HNO_3) is produced as a by-product.

$$La\,(OH)_3 \rightarrow La_2O_3 + H_2O \qquad (5)$$

In this step, lanthanum hydroxide decomposes to form lanthanum oxide (La_2O_3), which is the desired nanoparticle product. Water (H_2O) is also released during this decomposition reaction.

Synthesis of Polypyrrole (PPy)

Chemical Equation (not shown in the image but assumed to be polymerization)

$$n \text{ Pyrrole monomers} \rightarrow (PPy)n + nH+ \qquad (6)$$

This reaction represents the polymerization of pyrrole monomers into polypyrrole (PPy). In this process, multiple pyrrole monomers (n) bond together to form a long chain-like molecule, releasing protons (H+) in the process.

Formation of Nano composite: Chemical Equation

$$(PPy)\,n + La_2O_3 \rightarrow (La_2O_3\text{-}PPy) \text{ Nano composite} \qquad (7)$$

This step likely refers to the deposition of the previously synthesized polypyrrole (PPy) onto the lanthanum oxide nanoparticles (La_2O_3) to form a nano composite material. The exact nature of the bonding between PPy and La_2O_3 is not explicitly shown in the equation.

Synthesis of Polypyrrole and Composites

Establish a synthesis protocol for the fabrication of polypyrrole (PPy) and its composites, employing diverse techniques such as chemical polymerization or electrochemical methods. Focus on optimizing key reaction parameters, including temperature, reaction time, concentrations, and ratios, to attain the desired material properties. Fine-tuning these parameters is essential to harness the full potential of PPy and its composites, tailoring their characteristics for specific applications. Through systematic optimization, the synthesis process can be precisely tailored, ensuring enhanced performance and functionality in the resulting materials, making them well-suited for a range of applications in fields like sensors, actuators, or energy storage devices. The choice of starting materials plays a pivotal role in determining the material's properties and applications. Among the metal salts, Ferric Chloride ($FeCl_3$) stands out as a versatile oxidizing agent and dopant utilized in the oxidative polymerization of pyrrole. Its efficacy lies in its ability to facilitate the formation of a conductive and stable PPy structure. Another noteworthy metal salt is Iron (III) Tosylate, recognized for its effectiveness as a dopant, contributing to the enhancement of PPy's conductivity, ultimately yielding materials with high electrical performance. Polymeric dopants, such as Poly (styrene sulfonic acid) (PSS), offer a valuable avenue for improving solubility and conductivity in PPy.

Synthesis Protocol Establishment

Techniques Selection

To initiate the fabrication of polypyrrole (PPy) and its composites, diverse techniques such as chemical polymerization or electrochemical methods are employed. The selection of the synthesis method plays a crucial role in determining the material's properties and applications.

Parameter Optimization

A paramount focus is placed on optimizing key reaction parameters to achieve the desired material properties (Batteries *et al*., 2020; Cvek *et al*., 2022; El-Bery *et al*., 2021; Jia *et al*., 2021; Song *et al*., 2021) [1, 5, 7, 12, 17]. This involves fine-tuning parameters such as temperature, reaction time, concentrations, and ratios. The precision in adjusting these factors is essential to unlock the full potential of PPy and its composites, allowing for the tailoring of their characteristics to meet specific application requirements.

Systematic Optimization

Through systematic optimization, the synthesis process can be precisely tailored. This ensures enhanced performance and functionality in the resulting materials, rendering them well-suited for a diverse range of applications. Fields such as sensors, actuators, and energy storage devices can benefit from the tailored properties of the synthesized PPy and its composites.

Materials Selection

Metal Salts

The choice of starting materials plays a pivotal role in determining the material's properties and applications. Among the metal salts, two noteworthy options are considered:

Ferric Chloride ($FeCl_3$)

A versatile oxidizing agent and dopant utilized in the oxidative polymerization of pyrrole. Its efficacy lies in its ability to facilitate the formation of a conductive and stable PPy structure. The reaction between Ferric Chloride ($FeCl_3$) and polypyrrole involves the oxidative polymerization of pyrrole monomers. The chemical equation for this process can be represented as follows:

n Phyrrole monomers + $FeCl_3 \rightarrow ⟦(PPy)⟧n + nHCI$ (8)

In this equation

- (n) Represents the number of pyrrole monomers that polymerize to form the polypyrrole (PPy) chain.
- $FeCl_3$ serves as the oxidizing agent and dopant during the polymerization process. - HCl is generated as a by-product.

The overall reaction reflects the oxidative coupling of pyrrole monomers initiated by the oxidizing properties of Ferric Chloride, resulting in the formation of the polypyrrole polymer. This polymerization process leads to the creation of a conductive and stable PPy structure, where $FeCl_3$ acts as both an oxidizing agent and a dopant, contributing to the enhanced conductivity of the final material.

Iron (III) Tosylate

Recognized for its effectiveness as a dopant, Iron (III) Tosylate contributes to the enhancement of PPy's conductivity. This results in materials with high electrical performance, broadening the scope of potential applications.

The reaction between Iron (III) Tosylate and polypyrrole involves the doping process, where Iron (III) Tosylate serves as a dopant to enhance the electrical conductivity of the polypyrrole (PPy).

The chemical equation for this process can be represented as follows

PPy + Iron (III) Tosylate → Doped PPy (9)

In this equation:

- PPy represents the polypyrrole polymer.
- Iron (III) Tosylate serves as the dopant.

The specific chemical interactions between Iron (III) Tosylate and the polypyrrole chain may involve the incorporation of the iron ions into the PPy structure, leading to increased charge carriers and improved electrical conductivity. The dopant helps modify the electronic properties of PPy, making it more suitable for certain applications where enhanced conductivity is desired. The precise chemical details of this interaction may vary based on the conditions and the specific structural characteristics of the Iron (III) Tosylate used in the reaction (Bhadra *et al*., 2019; Boolchandani *et al*., 2018; El Alouani *et al*., 2019; Inamdar *et al*., 2018) [2, 3, 8, 11].

Polymeric Dopants

Polymeric dopants provide a valuable avenue for improving solubility and conductivity in PPy.

Two significant polymeric dopants are considered:

Poly (styrene sulfonic acid) (PSS)

PSS, when present during polymerization, enhances the material's electro active nature, promoting improved solubility, and better process ability.

The reaction between Poly (styrene sulfonic acid) (PSS) and polypyrrole involves the use of PSS as a dopant to enhance the solubility and conductivity of polypyrrole (PPy). The chemical equation for this process can be represented as follows:

PPy + PSS → Doped PPy (10)

In this equation:

- PPy represents the polypyrrole polymer.
- PSS serves as the polymeric dopant.

The specific chemical interactions involve the incorporation of PSS into the PPy structure. PSS is anionic, and its presence during the polymerization process enhances the solubility of PPy in water and improves its conductivity. The dopant plays a role in modifying the electronic properties of PPy, contributing to the electro activity of the material. The exact chemical details of this interaction can vary based on the conditions and the specific structural characteristics of the PSS used.

Characterization Techniques

Utilize diverse characterization methods to examine the structure, morphology, and properties of the synthesized materials. Employ Fourier-transform infrared spectroscopy (FTIR) to conduct structural analysis, providing insights into molecular composition. Additionally, utilize scanning electron microscopy (SEM) or transmission electron microscopy (TEM) for detailed morphological characterization, enabling a closer examination of surface features and particle arrangements. These analytical techniques collectively offer a comprehensive understanding of the synthesized materials, aiding in the assessment of their composition, structural integrity, and surface characteristics. The integration of FTIR, SEM, and TEM ensures a thorough evaluation, facilitating informed decisions for refining and optimizing the synthesis process for desired material outcomes.

FTIR Spectra

FTIR spectra, obtained through Fourier Transform Infrared Spectroscopy, reveal absorption bands linked to the sample's functional groups. Peaks signify molecular vibrations, crucial for discerning chemical bonds and elucidating structural characteristics. This analytical technique offers insights into the composition and configuration of molecules, facilitating identification and analysis of diverse compounds.

UV Spectra

UV spectra, stemming from Ultraviolet Spectroscopy, portray the absorption of light by molecules, elucidating electronic transitions. Peaks denote the presence and strength of distinct chromospheres or conjugated systems within the sample. This analytical method enables the examination of molecular structures and electronic configurations, aiding in the identification and characterization of compounds. Additionally, UV spectroscopy serves as a valuable tool in various fields, including chemistry, biology, and materials science, contributing to the understanding of molecular behaviour and interactions.

XRD Spectra

XRD spectra, derived from X-ray Diffraction, exhibit diffraction patterns stemming from the sample's crystal lattice. Peaks delineate the positions and intensities of diffraction peaks, facilitating the assessment of crystalline structure and phase composition. This analytical technique is invaluable in material science, mineralogy, and structural biology for characterizing crystalline materials. By analysing XRD spectra, researchers can discern information regarding lattice parameters, grain size, and preferred orientation, contributing to the elucidation of material properties and phase transformations. Moreover, X-ray diffraction serves as a powerful tool for investigating structural changes in compounds under various conditions.

TEM Images

TEM, or Transmission Electron Microscopy, delivers high-resolution images offering detailed views of a sample's microstructure. These images unveil intricate morphology, particle dimensions, and the distribution of nanoparticles or crystalline domains within the material. By capturing nanoscale features, TEM enables precise analysis of materials across various disciplines, including nanotechnology, materials science, and biology. This technique plays a pivotal role in elucidating fundamental properties of materials, such as atomic arrangements and defect structures. Moreover, TEM serves as a cornerstone for exploring novel materials and advancing our understanding of their structure-property relationships, driving innovation in diverse fields.

EIS Spectra

EIS, or Electrochemical Impedance Spectroscopy, portrays the sample's impedance reactions to alternating current across different frequencies. The accompanying graphs illustrate impedance magnitude and phase angle, offering valuable insights into electrical attributes such as conductivity, capacitance, and resistance. By analysing these spectra, researchers gain deeper understanding of electrochemical processes and the behaviour of materials in various environments, pivotal in fields like battery technology, corrosion science, and sensor development. EIS serves as a powerful diagnostic tool for studying interface phenomena, elucidating mechanisms of charge transfer, and optimizing performance of electrochemical systems, thereby driving advancements in energy storage and electro analytical techniques.

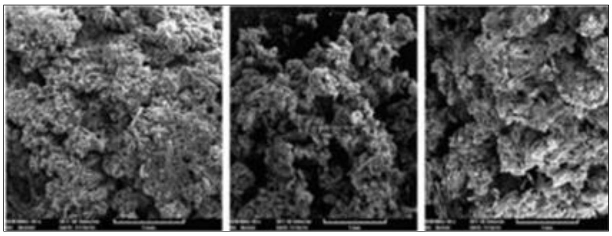

Fig 2: Microstructure of polypyrrole samples synthesized with ferric chloride as the oxidizing agent

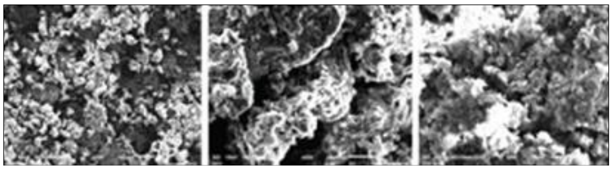

Fig 3: Microstructure of polypyrrole samples with polystyrene sulfonate

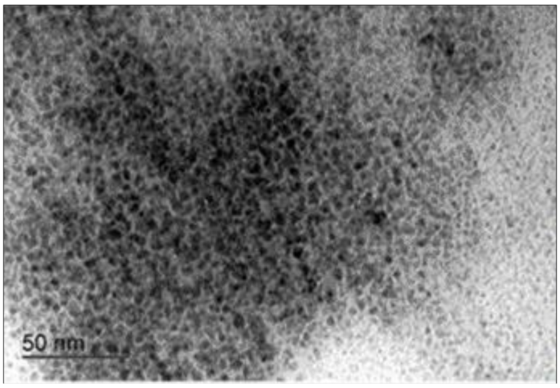

Fig 4: Transmission electron microscopy picture of polypyrrole doped with iron (III) chloride.

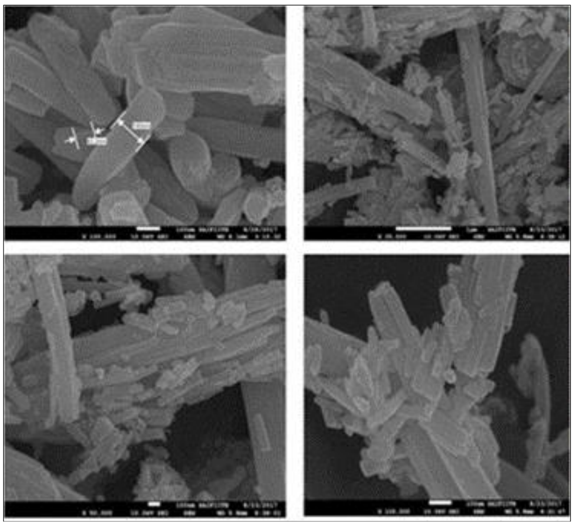

Fig 5: SEM images of La2O3

Optimization of Properties

Achieving optimal properties in synthesized materials requires meticulous parameter fine tuning. Systematic optimization of factors including temperature, time, concentrations, and ratios is crucial during synthesis. This iterative refinement ensures that resulting materials precisely meet desired specifications for specific applications. Precise control over these parameters is instrumental in tailoring properties such as conductivity, stability, and morphology. Continuous evaluation through characterization techniques like Fourier-transform infrared spectroscopy (FTIR) and microscopy informs the optimization process. By strategically adjusting synthesis parameters, researchers enhance overall performance, functionality, and applicability of materials, contributing to advancements in electronics, sensors, and materials science.

Application Studies

Application studies play a pivotal role in evaluating the real-world utility of synthesized materials. Researchers conduct systematic investigations to assess the performance and functionality of materials in specific applications, such as sensors, actuators, or energy storage devices. These studies involve rigorous testing, data analysis, and comparison with existing technologies. Application-focused research helps identify strengths, limitations, and potential enhancements, guiding further material optimization. Insights gained from these studies contribute to the development of innovative technologies, fostering advancements in diverse fields, from electronics to healthcare. Application-driven research ensures that synthesized materials align with practical requirements, promoting their successful integration into various industries.

Result and Discussion

Performance metrics serve as crucial benchmarks in evaluating the quality and characteristics of synthesized materials, such as polypyrrole composites. The diffraction angle (2θ) in X-ray crystallography provides insights into structural arrangements. Wavelengths, examined through UV-Visible spectroscopy, reveal the absorption behavior of composites. Temperature and reaction time influence kinetics and thermodynamics, affecting the final structure. Concentrations of reactants play a pivotal role in determining yield and composition. Ratios of pyrrole monomers to oxidizing/dopant agents impact conductivity. These metrics collectively enable a comprehensive assessment, guiding the optimization of synthesis parameters for desired properties in polypyrrole composites tailored for specific applications.

2θ (Degrees)

The diffraction angle, a fundamental metric in X-ray crystallography, serves as a powerful tool in elucidating the structural intricacies of polypyrrole composites. This metric, denoted as 2θ, captures the angular deviation of diffracted X-rays from their incident path. Through the analysis of X-ray diffraction patterns, it offers valuable insights into the arrangement of crystal planes within the composite, shedding light on the material's overall structural organization and orientation. By deciphering the diffraction angle, researchers can glean critical information about the crystalline characteristics of polypyrrole, facilitating a deeper understanding of its properties and guiding the optimization of synthesis processes for enhanced material performance.

Wavelengths

The term "Wavelengths" in the context of UV-Visible spectroscopy encompasses a spectrum of electromagnetic waves scrutinized to unravel the absorption behavior of polypyrrole composites. This metric provides a comprehensive exploration of how these materials interact with light across various wavelengths, offering intricate insights into electronic transitions within the composite structure. By probing different segments of the electromagnetic spectrum, UV-Visible spectroscopy allows researchers to discern specific absorption peaks and patterns. These revelations are instrumental in understanding the electronic properties of polypyrrole, guiding the design and optimization of composites for applications such as sensors, actuators, and energy storage devices.

Temperature (°C)

The synthesis temperature plays a pivotal role in shaping the kinetics and thermodynamics of the reaction process, exerting profound effects on the outcome of polypyrrole composite synthesis. This crucial parameter directly influences the rate of polymerization, dictating the speed at which monomers assemble into the polymeric structure. Moreover, the synthesis temperature intricately guides the thermodynamic stability of the reaction, impacting the equilibrium between reactants and products. As a result, the final structure of polypyrrole composites, including their morphology and crystal lenity, is profoundly influenced by the carefully controlled temperature conditions during synthesis, highlighting the critical importance of this parameter in tailoring material properties.

Reaction Time (hrs)

The metric of reaction time serves as a temporal gauge in the synthesis of polypyrrole composites, measuring the duration of the intricate process. This pivotal parameter directly impacts the extent of polymerization, delineating the period over which monomers transform into the polymeric structure. The duration of the reaction time intricately influences the size and morphology of the resulting polypyrrole composites. A prolonged reaction time may lead to higher degrees of polymerization, potentially yielding larger and more complex structures. Conversely, shorter reaction times may favor the formation of smaller, more controlled morphologies, showcasing the significant role that reaction time plays in tailoring the material's characteristics.

Concentrations (mol/L)

The metric of concentrations in the synthesis of polypyrrole composites embodies the molar concentration of reactants, a fundamental factor exerting substantial influence on the overall process. This critical parameter plays a pivotal role in determining the yield, composition, and inherent properties of the synthesized polypyrrole composites. The carefully controlled concentration of reactants directly impacts the stoichiometry of the reaction, influencing the ratio at which monomers polymerize and form the composite material. This, in turn, governs the final characteristics, structural features, and functional properties of the polypyrrole composites, underscoring the indispensable role of concentrations in shaping the outcome of the synthesis process.

Ratios PPy: Reactant

The ratio of pyrrole monomers to oxidizing/dopant agents, encapsulated in the metric of Ratios PPy: Reactant, articulates the stoichiometric intricacies governing the synthesis of polypyrrole composites. This pivotal ratio emerges as a determining factor, shaping the conductivity and various key characteristics of the resulting material. By delineating the exact proportions at which pyrrole monomers interact with oxidizing/dopant agents, this metric orchestrates the extent of polymerization and the distribution of charge carriers within the polypyrrole structure. Consequently, the carefully calibrated ratio stands as a fundamental parameter in tailoring the electronic properties and overall functionality of the synthesized polypyrrole composites.

Table1**:** X-ray Diffraction Patterns of Various Polypyrrole Composites.

2θ (Degrees)	PPy	PPy-(FeCl3) Composite	PPy- Iron (III) Tosylate Composite	PPy- La2O3 Composite	PPy-PSS Composite
20	1050	1125	1215	1213	1180
25	1550	1450	1630	1530	1540
30	2100	1850	1985	1988	1920
35	1850	2050	2255	2321	2100

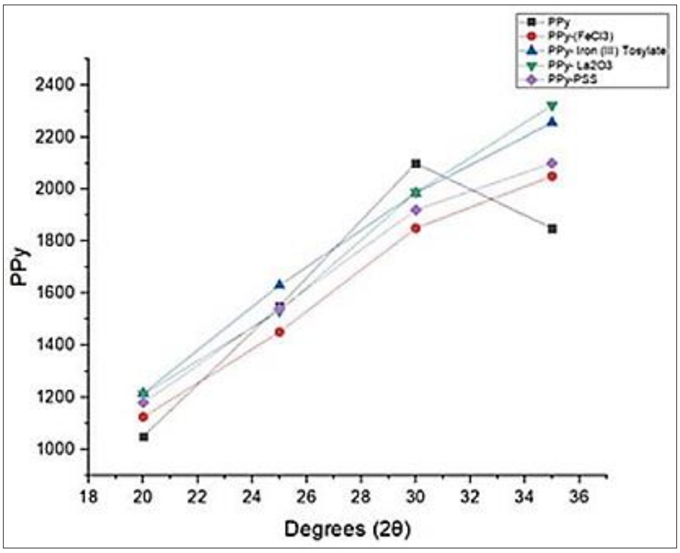

Fig 6: X-ray Diffraction Patterns of Various Polypyrrole

Composites

The table presents X-ray diffraction patterns for various polypyrrole (PPy) composites at different 2θ (degrees) values. Each composite, including PPy, PPy-FeCl$_3$, PPy-Iron (III) Tosylate, PPyLa$_2$O$_3$, and PPy-PSS, exhibits distinct peaks at varying 2θ values. These peaks signify the crystalline structures present within the composites. For example, at 20°, PPy-FeCl$_3$ composite shows a peak at 1125, indicating a specific crystalline arrangement, while at the same angle, PPyLa$_2$O$_3$ composite displays a peak at 1215, suggesting a different crystal structure. Analysing these patterns aids in understanding the structural characteristics and variations among different PPy composites, crucial for material characterization and applications.

Table 2: UV-Visible Absorption Spectra of Polypyrrole Composites at Varying Wavelengths

Wavelength (nm)	PPy	PPy-(FeCl3) Composite	PPy- La2O3 Composite	PPy- Iron (III) Tosylate Composite	PPy-PSS Composite
300	0.11	0.13	0.15	0.12	0.14
400	0.32	0.29	0.28	0.30	0.31
500	0.51	0.47	0.46	0.50	0.48
600	0.59	0.56	0.58	0.55	0.57

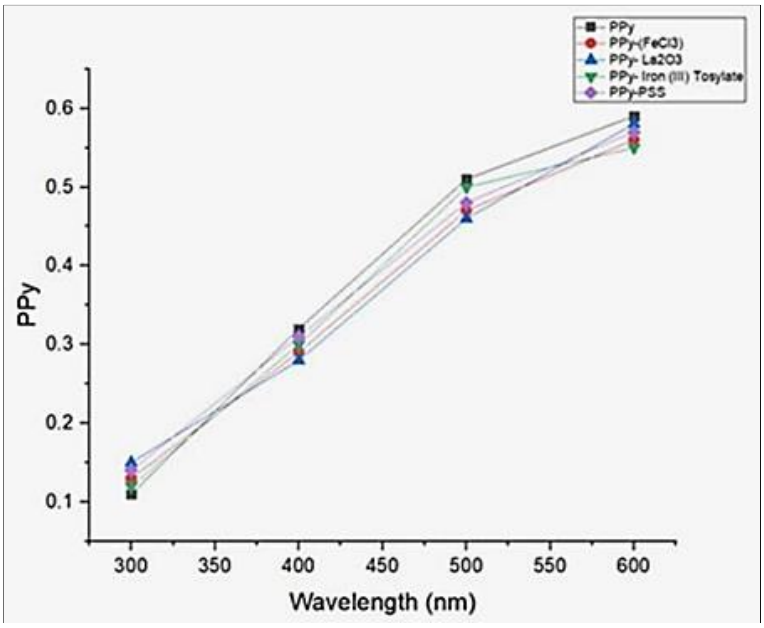

Fig 7: Polypyrrole Composites at Varying Wavelengths

The table illustrates the UV-Visible absorption spectra of various polypyrrole (PPy) composites across different wavelengths. Each composite, including PPy, PPy-FeCl$_3$, PPy-La$_2$O$_3$, PPyIron (III) Tosylate, and PPy-PSS, exhibits unique absorption values at varying wavelengths (measured in nm). For instance, at 300nm wavelength, PPy-La2O3 composite shows an absorption value of 0.15, indicating its propensity to absorb light at this wavelength. Similarly, at 400nm, PPy composite registers an absorption value of 0.32, suggesting its absorption capability at this wavelength. These absorption spectra provide insights into the optical properties and absorption characteristics of different PPy composites,crucial for various applications like sensors and photovoltaics.

Table 3: Table: Synthesis Conditions for Polypyrrole Composites with Varied Reactants

Composite	Temperature (°C)	Reaction Time (hrs)	Concentrations (mol/L)	Ratios PPy: Reactant
PPy	25	3	0.5	1:1
PPy-$FeCl_3$ Composite	30	4	0.6	1:1.2
PPy-Iron (III) Tosylate	35	5	0.7	1:1.5
PPy-PSS Composite	28	3	0.5	1:1.1
PPy- La_2O_3 Composite	27	6	0.8	1:1.3

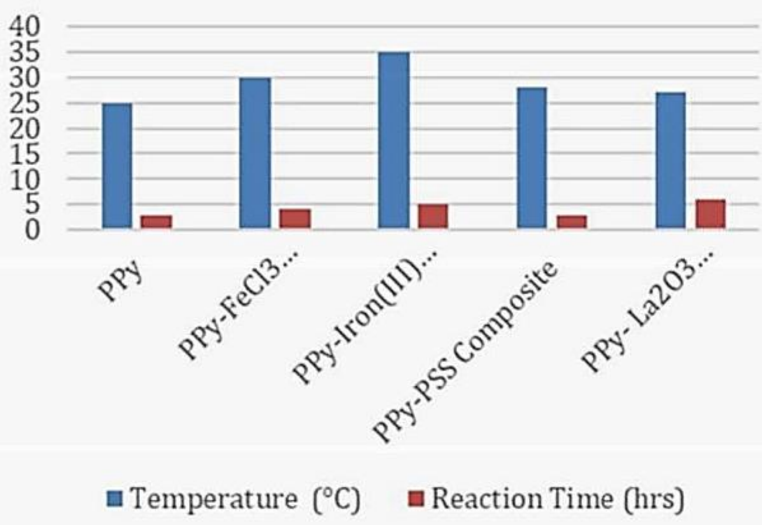

Fig 8: Performance Graph of Synthesis conditions for different Polypyrrole Composites.

The table outlines the synthesis conditions for various polypyrrole (PPy) composites using different reactants. Each composite is characterized by specific temperature, reaction time, reactant concentrations (in mol/L), and the ratio of PPy to the respective reactant. For instance, the synthesis of PPy-$FeCl_3$ composite occurs at 30°C for 4 hours with a concentration of 0.6 mol/L, maintaining a 1:1.2 ratio of PPy to $FeCl_3$. Similarly, other composites like PPy-Iron (III) Tosylate, PPy-PSS, and PPy-La_2O_3 follow distinct conditions. These details provide a comprehensive understanding of the experimental parameters crucial for synthesizing diverse PPy composites.

Conclusion

In conclusion, this study has demonstrated the significance of optimizing synthesis conditions for the creation of polypyrrole (PPy) composites with tailored properties. Through systematic investigation of temperature, reaction time, concentrations, and ratios, we have elucidated their profound impact on the structural and electrical characteristics of the synthesized materials. Our findings reveal that precise control over synthesis parameters results in enhanced crystallinity, improved electronic properties, and customized morphologies of PPy composites.The analysis of X-ray Diffraction (XRD) patterns provided valuable insights into the crystallographic structure and orientation of the composites, while UV-Visible spectroscopy elucidated their optical properties and electronic transitions. These characterization techniques underscore the importance of comprehensive material analysis in understanding the behavior and potential applications of PPy composites.Furthermore, the exploration of various reactants, including metal salts and polymeric dopants, has expanded our understanding of the versatility and tunability of PPy-based materials. Notably, the investigation of the PPy-La_2O_3 composite presents novel insights into its structural and optical properties, offering promising avenues for further research and application development, this study contributes essential knowledge for the systematic development and enhancement of PPy composites, paving the way for their utilization in diverse fields such as sensors, actuators, and energy storage systems. Continued research in this area holds great promise for advancing materials science and technology towards innovative and sustainable solutions.

References

1. Batteries PL, Hong X, Liu Y, Li Y, Wang X, Fu J, *et al*. Application Progress of Polyaniline, Polypyrrole and Polythiophene in Lithium-Sulfur Batteries Xiaodong. Polymers. 2020;12:331.
2. Bhadra J, Popelka A, Abdulkareem A, Ahmad Z, Touati F, Al-Thani N. Fabrication of polyaniline-graphene/polystyrene nanocomposites for flexible gas sensors. RSC Advances. 2019;9(22):12496-12506. https://DOI.org/10.1039/c9ra00936a
3. Boolchandani S, Srivastava S, Vijay YK. Preparation of InSe Thin Films by Thermal Evaporation Method and Their Characterization: Structural, Optical, and Thermoelectrical Properties. Journal of Nanotechnology; c2018. https://DOI.org/10.1155/2018/9380573
4. Chemistry IJ of A. Retracted: Electrochemical Preparation of Nanocatalysts and Their Application in Electrocatalysis. International Journal of Analytical Chemistry. 2023;1-1. https://DOI.org/10.1155/2023/9867946
5. Cvek M, Jamatia T, Suly P, Urbanek M, Torres-Mendieta R. Stable Magnetorheological Fluids Containing Bidisperse Fillers with Compact/Mesoporous Silica Coatings. International Journal of Molecular Sciences. 2022;23(19). https://DOI.org/10.3390/ijms231911044

6. Díaz-Muñoz LL, Reynel-Ávila HE, Mendoza-Castillo DI, Bonilla-Petriciolet A, Jáuregui-Rincón J. Preparation and Characterization of Alkaline and Acidic Heterogeneous Carbon-Based Catalysts and Their Application in Vegetable Oil Transesterification to Obtain Biodiesel. International Journal of Chemical Engineering; c2022. https://DOI.org/10.1155/2022/7056220
7. El-Bery HM, Salah MR, Ahmed SM, Soliman SA. Efficient non-metal based conducting polymers for photocatalytic hydrogen production: comparative study between polyaniline, polypyrrole and PEDOT. RSC Advances. 2021;11(22):13229-13244. https://DOI.org/10.1039/d1ra01218e
8. El Alouani M, Alehyen S, El Achouri M, Taibi M. Preparation, Characterization, and Application of Metakaolin-Based Geopolymer for Removal of Methylene Blue from Aqueous Solution. Journal of Chemistry. 2019. https://DOI.org/10.1155/2019/4212901
9. Guan H, Xu Y, Ma C, Zhao D. Pharmacology, Toxicology, and Rational Application of Cinnabar, Realgar, and Their Formulations. Evidence-Based Complementary and Alternative Medicine. 2022. https://DOI.org/10.1155/2022/6369150
10. Hao L, Dong C, Zhang L, Zhu K, Yu D. Polypyrrole Nanomaterials: Structure, Preparation and Application. Polymers. 2022;14(23). https://DOI.org/10.3390/polym14235139
11. Inamdar HK, Sridhar BC, Sasikal M, Ambika Prasad MVN. Structural and Optical Properties of Polypyrrole/NiO Doped Nanocomposites. Journal of Nanoscience and Technology. 2018;4(3):400-401. https://DOI.org/10.30799/jnst.112.18040308
12. Jia J, Liu Y, Sun S. Preparation and Characterization of Chitosan/Bentonite Composites for Cr(VI) Removal from Aqueous Solutions. Adsorption Science and Technology. 2021. https://DOI.org/10.1155/2021/6681486
13. Kamalov A, Shishov M, Smirnova N, Kodolova-Chukhontseva V, Dobrovol'skaya I, Kolbe K, *et al*. Influence of Electric Field on Proliferation Activity of Human Dermal Fibroblasts. Journal of Functional Biomaterials. 2022;13(3). https://DOI.org/10.3390/jfb13030089
14. Krishna Prasad S, Dayanand S, Rajesh M, Nagaral M, Auradi V, Selvaraj R. Preparation and Mechanical Characterization of TiC Particles Reinforced Al7075 Alloy Composites. Advances in Materials Science and Engineering. 2022. https://DOI.org/10.1155/2022/7105189
15. Nanoparticles T, Alharbi KH, Alharbi W, Farea MO, Menazea AA. Pyrrolidone/Carboxymethyl Cellulose Blend Scattered by. Ono T. Tent Space Approach of Morrey Spaces and Their Application to Duality and Complex Interpolation. Journal of Function Spaces. 2023;2023:1-15. https://DOI.org/10.1155/2023/5822846
16. Saliba EP, Barnes AB. The Clebsch-Gordan Coefficients and Their Application to Magnetic Resonance. Concepts in Magnetic Resonance Part A: Bridging Education and Research. 2022. https://DOI.org/10.1155/2022/1143341
17. Song X, Zhang Y, Cui X, Liu F, Zhao H. Preparation and Characterization of Chabazite from Construction Waste and Application as an Adsorbent for Methylene Blue. Adsorption Science and Technology. 2021. https://DOI.org/10.1155/2021/9994079
18. Sonika, Verma SK, Samanta S, Srivastava AK, Biswas S, Alsharabi RM, Rajput S. Conducting Polymer Nanocomposite for Energy Storage and Energy Harvesting Systems. Advances in Materials Science and Engineering. 2022. https://DOI.org/10.1155/2022/2266899
19. Tu A, Ye J, Wang B. Neutrosophic Number Optimization Models and Their Application in the Practical Production Process. Journal of Mathematics. 2021. https://DOI.org/10.1155/2021/6668711
21. Wang JY, Wang YP, Liu L, Na J. Hesitant Bipolar-Valued Fuzzy Soft Sets and Their Application in Decision Making. Complexity. 2020. https://DOI.org/10.1155/2020/6496030
22. Wang S, Wang Y, Li X, Liu L, Xing H, Zhang Y. Big Data-Based Boring Indexes and Their Application during TBM Tunneling. Advances in Civil Engineering. 2021. https://DOI.org/10.1155/2021/2621931
23. Yi S, Zaoli Y, Xuemei X, Harish G. Complex System Models and Their Application in Industrial Cluster and Innovation Systems. Complexity. 2022. https://DOI.org/10.1155/2022/9790151
24. Yussuf A, Al-Saleh M, Al-Enezi S, Abraham G. Synthesis and Characterization of Conductive Polypyrrole: The Influence of the Oxidants and Monomer on the Electrical, Thermal, and Morphological Properties. International Journal of Polymer Science. 2018. https://DOI.org/10.1155/2018/4191747
25. Zhou H. Electrochemical Preparation of Nanocatalysts and Their Application in Electrocatalysis. International Journal of Analytical Chemistry. 2022. https://DOI.org/10.1155/2022/9884302