

Article

Weavable and Robust Covalent Organic Framework Composite Yarns via Conjugated Electrospinning for Enhanced Dye Adsorption

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Abstract

Covalent Organic Frameworks (COFs) are renowned for their high crystallinity and tailored porosity, yet their intractable powder form and poor processability severely limit practical deployment. While electrospun nanofiber membranes offer a pathway to macro-scale COF composites, they often suffer from isotropic mechanical weakness and lack textile processability. Herein, we report a conjugated electrospinning strategy integrated with in situ solvothermal synthesis to fabricate continuous, weavable, and mechanically robust Polyacrylonitrile@Covalent Organic Framework-H (PAN@COF-H) composite yarns. The resulting yarns feature a unique hierarchical architecture where COF-H crystals uniformly coat the surface of oriented nanofibers. This design endows the material with a high specific surface area (94.9 m²/g) and exceptional tensile strength (10 MPa), representing a significant improvement over conventional random electrospun mats. Benefiting from the intrinsic porosity of COF-H and the hydrophilic nature of the composite, the yarns achieve a 73.76% removal rate for Rhodamine B (RhB) within 4 h. Crucially, the material retains over 33.36% of its adsorption capacity after five consecutive cycles, demonstrating outstanding durability. This study bridges the gap between microscopic COF crystals and macroscopic textile architectures, offering a versatile platform for deployable environmental remediation technologies.

Keywords: electrospinning yarn; Covalent Organic Frameworks (COFs); in situ growth; dye adsorption; weavable materials



Academic Editor: Anita Ioana Visan

Received: 2 July 2026

Revised: 23 July 2026

Accepted: 27 July 2026

Published: 30 July 2026

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1. Introduction

Covalent Organic Frameworks (COFs) represent a groundbreaking class of crystalline porous polymers, constructed from lightweight elements linked by strong covalent bonds [1–5]. Since their first report by Yaghi and co-workers in 2005, COFs have garnered immense attention due to their atomically precise pore structures, ultrahigh specific surface areas, and exceptional chemical stability [6–10]. These intrinsic features render them exceptionally promising candidates for addressing pressing global challenges in environmental remediation, particularly in the removal of organic pollutants and toxic heavy metals from wastewater [9–13]. For instance, functionalized COFs featuring specific active sites—such as carboxylic acid (–COOH) or sulfonic acid (–SO₃H) groups—exhibit remarkable affinity

for cationic dyes like Rhodamine B (RhB) and Methylene Blue (MeB) through synergistic mechanisms involving electrostatic attraction, π - π stacking, and hydrogen bonding [14–16]. Furthermore, their ordered microchannels facilitate rapid mass transport, enabling adsorption kinetics that often surpass those of conventional activated carbons and amorphous polymers [17,18]. Despite this immense potential, the practical deployment of COFs in real-world water treatment scenarios remains severely hampered by a critical bottleneck: their intractable morphology [19–22].

Typically synthesized as brittle, microcrystalline powders, COFs are insoluble and infusible, making them notoriously difficult to process into macroscopic devices [23–25]. This “powder dilemma” leads to challenges in recovery, regeneration, and handling within flow systems [26–29]. To overcome this, researchers have explored integrating COFs with supporting substrates [30,31]. Among these, electrospinning has emerged as a versatile technique to produce nanofiber membranes (NFMs) embedded with COF particles or coatings [31–36]. While these composite membranes successfully provide a macroscopic form and prevent the loss of fine COF powders, they inherit the fundamental drawbacks of conventional electrospun mats: a lack of directional mechanical strength and structural isotropy. The random entanglement of fibers results in materials that are mechanically weak (often <1 MPa in tensile strength) and, crucially, lack the “weavability” required for integration into conventional textiles [37,38]. This limitation prevents the creation of complex, wearable, or large-scale filtration systems, thereby restricting the application scope of COF-based adsorbents in next-generation smart textiles and deployable environmental technologies [39–42].

To overcome the limitations of conventional electrospun membranes, we present a paradigm shift from “random mats” to “oriented yarns” by developing a conjugated electrospinning strategy coupled with in situ solvothermal synthesis. This approach utilizes oppositely charged spinnerets to generate axially aligned nanofiber bundles, which are subsequently functionalized with COF-H crystals in situ within a high-vacuum thick-walled reactor. Unlike previous reports where COFs merely act as dispersed fillers, our method achieves a uniform, conformal coating of COF-H that fully encapsulates the individual nanofibers while preserving the orientational order of the yarn [43–47]. This unique architectural design synergistically combines the high porosity of COFs with the superior mechanical integrity of oriented fibrous assemblies [48–50]. Consequently, the resulting PAN@COF-H composite yarns achieve a tensile strength of 10 MPa, orders of magnitude higher than that of typical isotropic COF membranes, while maintaining excellent flexibility and weavability.

In this study, we systematically characterize the crystallinity, morphology, and pore structure of the composite yarns. Three prominent merits make PAN an ideal substrate in this system: (1) its excellent spinnability for producing continuous, flexible nanofiber yarns via electrospinning; (2) its good thermal stability compatible with the high-temperature solvothermal synthesis of COFs; and (3) its relatively inert backbone, which ensures that the adsorption performance is primarily attributed to the functional COF-H coating rather than the substrate itself. The adsorption performance is evaluated using cationic dye (RhB) as a model pollutant. The selection of Rhodamine B (RhB), a cationic dye, was primarily based on the intrinsic physicochemical properties of the as-synthesized COF-H framework. COF-H is constructed from 1,3,5-triformylphloroglucinol (TFP) and *p*-phenylenediamine (Pa-H), forming an imine-linked ($-C=N-$) framework. During the synthesis and in aqueous environments, the imine bonds and the residual hydroxyl groups within the pores can interact with water molecules, which tends to render the framework surface negatively charged or electron-rich. Consequently, the composite yarn exhibits a strong electrostatic affinity towards cationic dyes like RhB. We demonstrate that the hydrophilic nature of

the COF-H coating and the hierarchical pore structure enable rapid water permeation and efficient dye capture, achieving a 73.76% removal rate for RhB within 4 h. Crucially, benefiting from the robust interfacial adhesion between the PAN substrate and the COF layer, the material retains over 33.36% of its adsorption capacity after five consecutive cycles, highlighting its outstanding durability. This work establishes a versatile platform for bridging the gap between microscopic COF crystals and macroscopic textile architectures, paving the way for deployable environmental remediation technologies.

2. Materials and Methods

2.1. Experimental Materials

Polypropylene nitrile (PAN, $M_n = 150,000$ g/mol) was purchased from Shanghai Macklin Biochemical Co., Ltd., Shanghai, China. 1,3,5-Triformylphloroglucinol (TFP) and p-phenylenediamine (Pa-H) were acquired from Shanghai Aladdin Biochemical Technology Co., Ltd., Shanghai, China. N,N-Dimethylformamide (DMF, analytical grade), 1,4-dioxane, mesitylene (1,3,5-trimethylbenzene), glacial acetic acid, acetone, and ethanol were supplied by Shanghai National Pharmaceutical Group Chemical Reagent, Shanghai, China. The dye Rhodamine B (RhB) was also obtained from commercial sources. All chemicals were used as received without further purification. Deionized water was used in all experiments.

2.2. Preparation of PAN-Pa-H Composite Yarns

The precursor solution for electrospinning was prepared by dissolving 0.75 g of PAN and 0.5 g of Pa-H powder in 4.25 g of DMF solvent, followed by magnetic stirring for 8 h to ensure complete dissolution and homogeneity. Conjugated electrospinning was performed using two syringes filled with the homogeneous solution. The spinning parameters were set as follows: applied voltage of 8 kV, injection speed of 0.4 mL/h, bell-mouth rotation speed of 40 r/min, and winding speed of 2 r/min. Under these conditions, continuous and oriented PAN/Pa-H composite nanofiber yarns were directly collected.

2.3. Synthesis of PAN-COF-H Fiber

The in situ growth of COF-H on the surface of composite yarns was carried out via a solvothermal method. Notably, a ‘weave-first-functionalize-later’ strategy was adopted. The as-spun PAN/Pa-H yarns were first woven into desired fabric structures prior to the solvothermal reaction. This approach prevents potential damage to the fragile woven structure during the vigorous stirring or shaking often associated with in situ growth processes and ensures the structural integrity of the final textile product. Typically, 63 mg (0.3 mmol) of TFP monomer was added to a high-vacuum thick-walled reaction bottle containing a mixed solvent of 1,4-dioxane and mesitylene (3 mL, $v/v = 1:1$) and 0.5 mL of 3 M acetic acid. After sonication for 10 min, the mixture was frozen in liquid nitrogen. Subsequently, 96 mg of the as-prepared PAN/Pa-H composite yarn was immersed into the frozen mixture. The system was evacuated and backfilled with nitrogen three times to ensure an oxygen-free environment, then sealed under vacuum. The reaction proceeded at 120 °C for 72 h. After cooling to room temperature, the resulting PAN-COF-H composite yarns were washed sequentially with acetone, deionized water, and ethanol, and finally dried under vacuum at 120 °C overnight.

2.4. Characterization of PAN-COF-H Fibers

The morphology and microstructure of the composite yarns were observed using a Phenom Pure desktop Scanning Electron Microscope (SEM, Phenom Pure, Eindhoven, The Netherlands) at an acceleration voltage of 10 kV. Transmission Electron Microscopy (TEM) was performed on a JEM-2100Plus instrument (JEOL, Akishima, Japan). X-ray

Diffraction (XRD, Bruker D8 Advance, Bruker AXS, Billerica, MA, USA) patterns were recorded on a Bruker D8 Advance diffractometer with Cu K α radiation ($\lambda = 1.5406 \text{ \AA}$) over a 2θ range of $2\text{--}40^\circ$. Fourier Transform Infrared (FT-IR, Fluorlog-QM, HORIBA Instruments Incorporated, Piscataway, NJ, USA) spectra were obtained using a Thermo Scientific Nicolet iS50 spectrometer (Waltham, MA, USA) in the range of $4000\text{--}500 \text{ cm}^{-1}$. Nitrogen adsorption–desorption isotherms were measured at 77 K using a Micromeritics ASAP 2020 Plus HD88 analyzer. The Brunauer–Emmett–Teller (BET, Micromeritics ASAP 2460-2M, Micromeritics, Norcross, GA, USA) method was used to calculate the specific surface area. Tensile tests were conducted on an Instron 5967 universal testing machine (Tokyo, Japan). Static water contact angles were measured using an OCA 25 optical tensiometer (DataPhysics Instruments GmbH, Filderstadt, Germany).

2.5. Application of Dye Adsorption for PAN-COF-H Fibers

The adsorption performance of the PAN@COF-H composite yarns was evaluated using Rhodamine B (RhB) as model pollutants. Typically, 10 mg of the composite yarn was immersed in 10 mL of dye solution (0.1 mmol/L) at room temperature. At predetermined time intervals, 3 mL of the solution was withdrawn and analyzed using a UV-Vis spectrophotometer (Hitachi U-3900H, Tokyo, Japan). The adsorption efficiency (ϵ) was calculated based on the change in concentration. For the recycling test, the used yarns were regenerated by immersion in ethanol until the solution became colorless, followed by washing with deionized water and drying at 60°C before the next cycle.

3. Results

3.1. Morphology and Structural Characterization of PAN@COF-H

Conjugated electrospinning was employed to fabricate continuous PAN/Pa-H composite yarns, as illustrated in Figure 1a. Optical images reveal that the pristine yarns possess a white appearance and exhibit exceptional flexibility, readily allowing for knotting and bending without fracturing (Figure 1b). Scanning electron microscopy (SEM) characterization (Figure 1e,f) demonstrates a uniform fiber distribution with high axial orientation; quantitative analysis indicates an average fiber diameter of approximately 645 nm. Crucially, the yarn surface is smooth and free of beads or particulate defects, confirming the high quality of the electrospinning process. Subsequently, an in situ solvothermal strategy was utilized to achieve the uniform growth of COF-H crystals on the fiber surface, resulting in a distinct color transition to red (Figure 1c). Notably, the composite yarns retained their structural integrity and flexibility post-synthesis. Furthermore, a “weave-first-functionalize-later” strategy was adopted to construct PAN@COF-H woven fabrics with regular macrostructures (Figure 1d), offering a novel paradigm for functional textile manufacturing. SEM images of the final product (Figure 1g,h) reveal that the original fiber morphology is almost entirely obscured by a dense, conformal coating of COF-H crystals, unequivocally verifying the successful in situ loading of the crystalline framework.

The crystalline structure of the synthesized PAN@COF-H composite yarns was first investigated by X-ray diffraction (XRD). As shown in Figure 2a, the composite exhibits distinct diffraction peaks at $2\theta = 4.9^\circ$, 8.42° , and 26.56° , which perfectly match the characteristic reflections of COF-H reported in the literature, corresponding to the (100), (210), and (001) crystallographic planes, respectively [51]. Additionally, a peak at $2\theta = 17.26^\circ$ is indexed to the typical diffraction of polyacrylonitrile (PAN), confirming the coexistence of both components in the composite. For comparison, the XRD pattern of pristine COF-H powder is presented in Figure 2b, showing similar characteristic peaks.

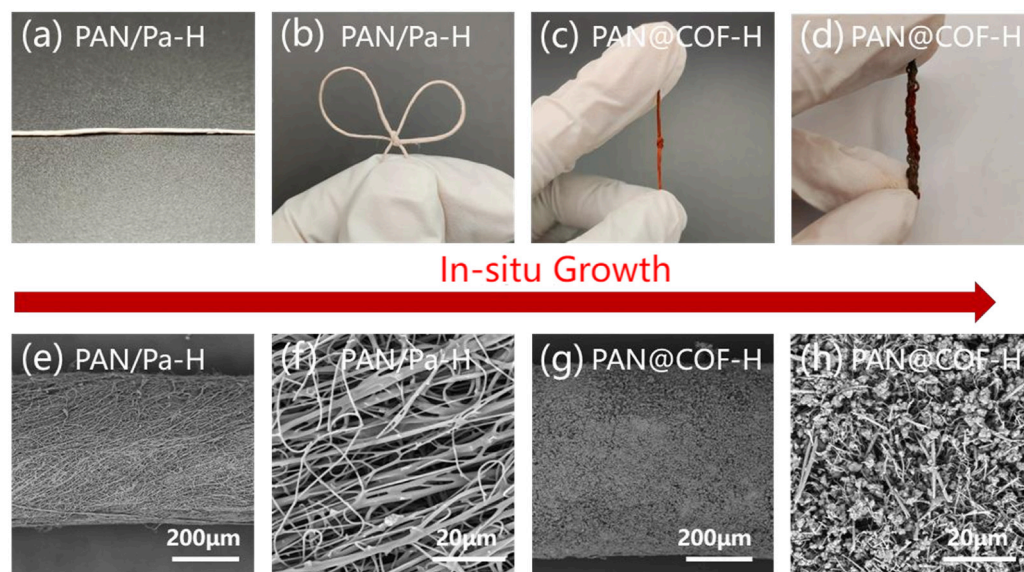


Figure 1. (a) Physical image of PAN/Pa-H yarn; (b) knot image of PAN/Pa-H yarn; (c) photograph of the as-synthesized PAN@COF-H composite yarn; (d) photograph of a PAN@COF-H woven fabric constructed using the ‘weave-first-functionalize-later’ strategy, demonstrating the material’s macroscopic processability; (e) SEM image of PAN/Pa-H yarn; (f) local magnification of the SEM image of PAN/Pa-H yarn; (g) SEM image of PAN@COF-H composite yarn; (h) higher magnification of the PAN@COF-H composite yarn.

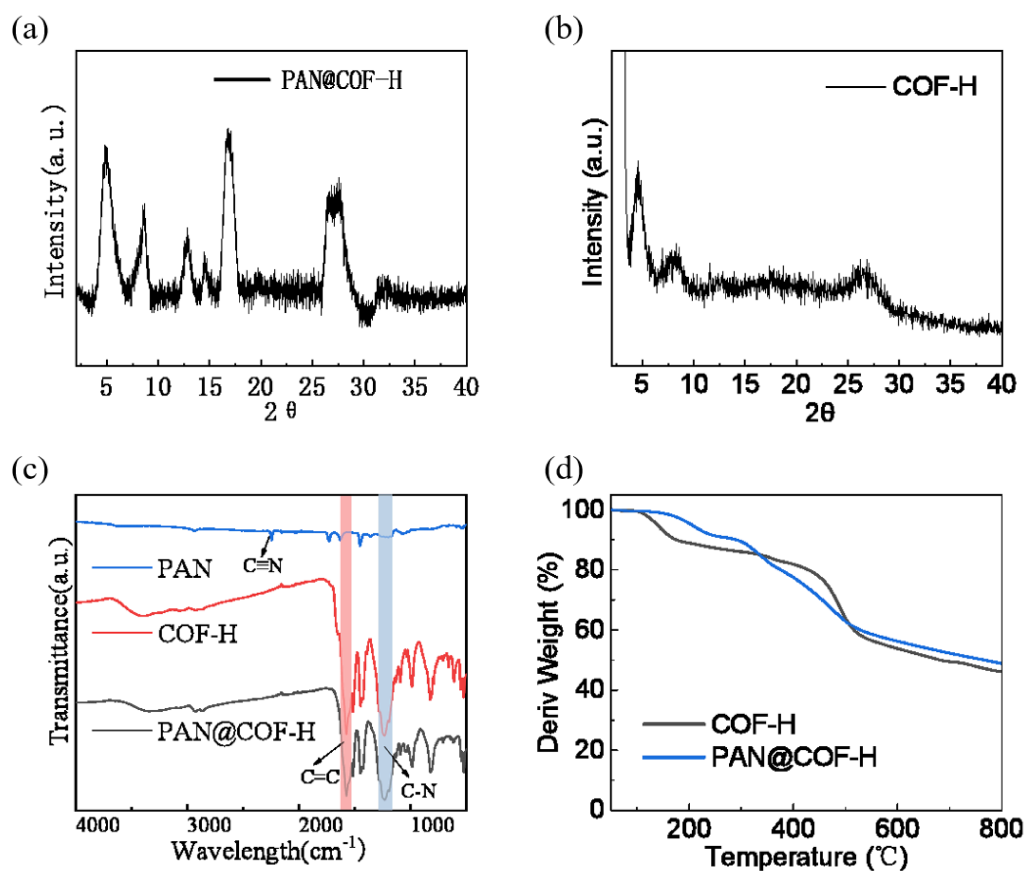


Figure 2. Structural and thermal characterization of PAN@COF-H composite yarns. (a) X-ray diffraction (XRD) pattern of PAN@COF-H; (b) XRD pattern of pristine COF-H powder for comparison. (c) Fourier-transform infrared (FT-IR) spectra of PAN, COF-H, and PAN@COF-H. (d) Thermogravimetric analysis (TGA) curves of COF-H and PAN@COF-H.

Further chemical structure analysis was performed using Fourier-transform infrared (FT-IR) spectroscopy (Figure 2c). Compared with pure PAN, the characteristic absorption peak of the nitrile group ($\text{-C}\equiv\text{N}$) at 2242 cm^{-1} completely disappears in the PAN@COF-H spectrum. This strongly suggests that COF-H has grown uniformly and completely over the PAN fiber surface, fully covering the nitrile groups. Moreover, the appearance of strong absorption bands at 1570 cm^{-1} ($\text{C}=\text{C}$ stretching) and 1232 cm^{-1} ($\text{C}-\text{N}$ stretching) in both COF-H powder and PAN@COF-H confirms the successful synthesis and structural integrity of the COF-H layer. The comparable peak intensities between PAN@COF-H and pure COF-H further validate the formation of a complete COF-H coating on PAN fibers.

Thermal stability is critical for practical applications of textile materials. Thermogravimetric analysis (TGA) was conducted to evaluate the thermal behavior of COF-H and PAN@COF-H. As depicted in Figure 2d, both samples exhibit similar weight loss profiles, indicating that the composite retains the thermal stability of pristine COF-H. The slight differences in the derivative weight loss curves suggest the presence of PAN core, but overall, the COF-H shell remains stable up to high temperatures, supporting its potential use in high-temperature environments.

The textural properties of PAN@COF-H composite yarns were further investigated by N_2 adsorption–desorption analysis (Figure 3). As shown in Figure 3a, the isotherm of PAN@COF-H exhibits a typical Type I behavior with a steep uptake at low relative pressures ($P/P_0 < 0.4$), which is characteristic of microporous materials. The calculated BET surface area is $94.9\text{ m}^2\text{ g}^{-1}$, indicating a highly porous structure. In contrast, pristine PAN shows negligible adsorption capacity, confirming its non-porous nature. The pore size distribution (PSD), derived from the desorption branch using the Barrett–Joyner–Halenda (BJH) method, is presented in Figure 3b. PAN@COF-H displays a narrow pore size distribution centered at approximately 1.1–1.3 nm, which closely matches the PSD of pure COF-H powder. This consistency demonstrates that the in situ growth of COF-H on PAN fibers preserves the intrinsic pore architecture of the COF, and the presence of PAN does not disrupt the crystalline framework or porosity of COF-H. Such well-defined microporosity endows the composite yarns with great potential for adsorption, separation, and catalytic applications.

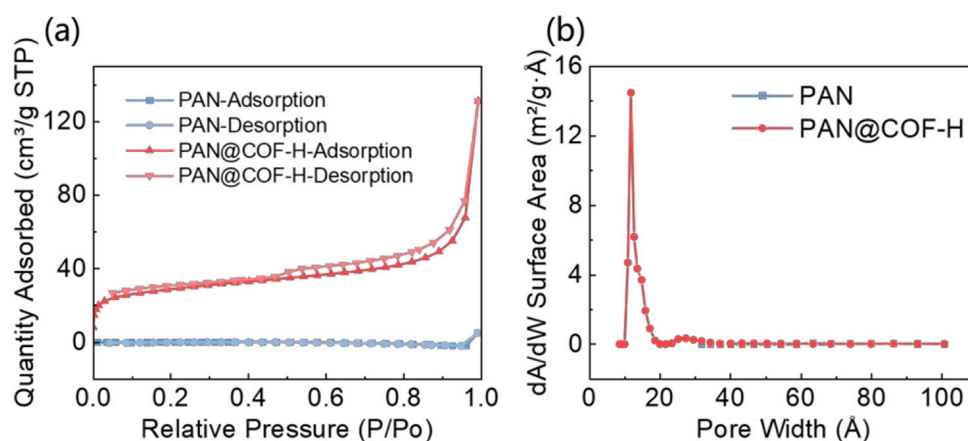


Figure 3. (a) BET specific surface area image of PAN fibers and PAN@COF-H fiber; (b) BET pore size distribution image of PAN and PAN@COF-H fiber.

To investigate the mechanical properties of PAN@COF-H nanofiber yarns, tensile tests were conducted, and the results are presented in Figure 4a. The experimental data reveal that the PAN/Pa-H composite yarns exhibit excellent mechanical performance, achieving a tensile stress of 35 MPa and a tensile strain of 65%. In contrast, the PAN@COF-H composite yarns also demonstrate decent mechanical properties, with a tensile stress of

10 MPa and a tensile strain of 16%. The tensile stress of PAN@COF-H is reduced by 71.4% compared to the PAN/Pa-H precursor, which is primarily attributed to the increased fiber diameter resulting from the in situ growth of COF-H on the fiber surface. This superior mechanical performance is mainly ascribed to the high degree of fiber orientation during the electrospinning process. Under the electric field and stretching device, fibers align along the axial direction, forming a highly oriented structure that significantly enhances the mechanical strength along the orientation direction. Notably, compared to the electrospun nanofiber membranes prepared under the same material system, the nanofiber yarns exhibit even more excellent tensile strength due to their higher orientation degree and more regular fiber arrangement.

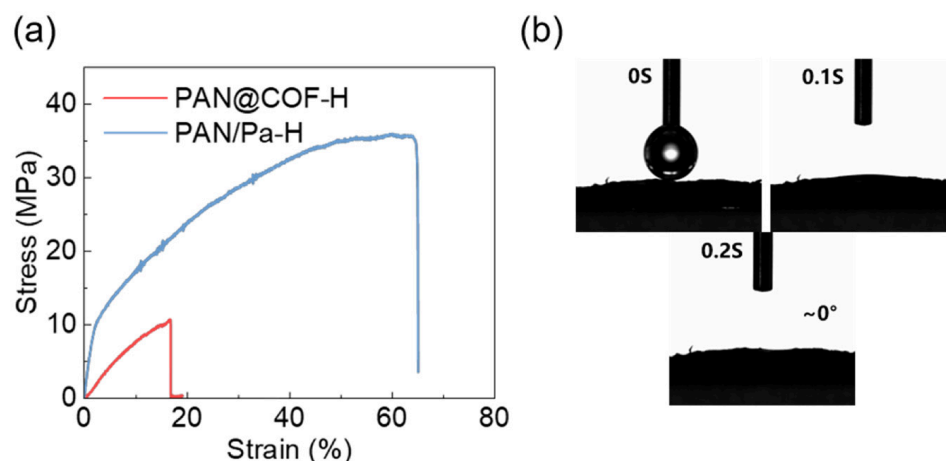


Figure 4. (a) Stress–strain curve image of PAN fibers; (b) water contact angle image of PAN fibers.

The wettability of the PAN@COF-H yarns was further evaluated by water contact angle (WCA) measurements, as shown in Figure 4b. A droplet is almost completely absorbed within 0.2 s after contacting the PAN@COF-H yarn, with the WCA approaching 0°. This superhydrophilic behavior shows little change compared to the PAN@COF-H nanofiber membrane. The reason lies in the fact that the COF-H crystals grown on the yarn surface fill the inter-fiber gaps, while still leaving abundant vertical pores on the yarn surface, thereby maintaining the highly porous and hydrophilic structure.

3.2. Dye Adsorption Performance

The adsorption performance of the as-prepared PAN@COF-H yarn toward RhB was systematically investigated via time-dependent UV-Vis spectroscopy. As illustrated in Figure 5a, the characteristic absorption peak of RhB at approximately 554 nm decreased progressively with increasing contact time, visually confirming the efficient capture capability of the composite fiber. The corresponding adsorption rate curve (Figure 5b) revealed a rapid adsorption phase within the initial 60 min, followed by a plateau, indicating the saturation of active sites on the COF-H shell. To elucidate the underlying adsorption mechanism, pseudo-first-order and pseudo-second-order kinetic models were employed to fit the experimental data (Figure 5c,d). The pseudo-second-order model exhibited a significantly higher correlation coefficient compared to the pseudo-first-order model, suggesting that the adsorption process is primarily governed by chemisorption, likely involving π - π stacking interactions between the aromatic frameworks of COF-H and the RhB molecules. Furthermore, the reusability of PAN@COF-H yarn was evaluated through five consecutive adsorption–desorption cycles. While the UV-Vis spectra (Figure 5e) showed a slight decline in peak intensity over cycles, the quantitative analysis (Figure 5f) indicated that the adsorption capacity remained at 33.26% of the initial value even after the fifth cycle. This

moderate reduction in efficiency can be attributed to the partial occupation or structural degradation of pores during the regeneration process, yet the material still demonstrates acceptable potential for repeated use.

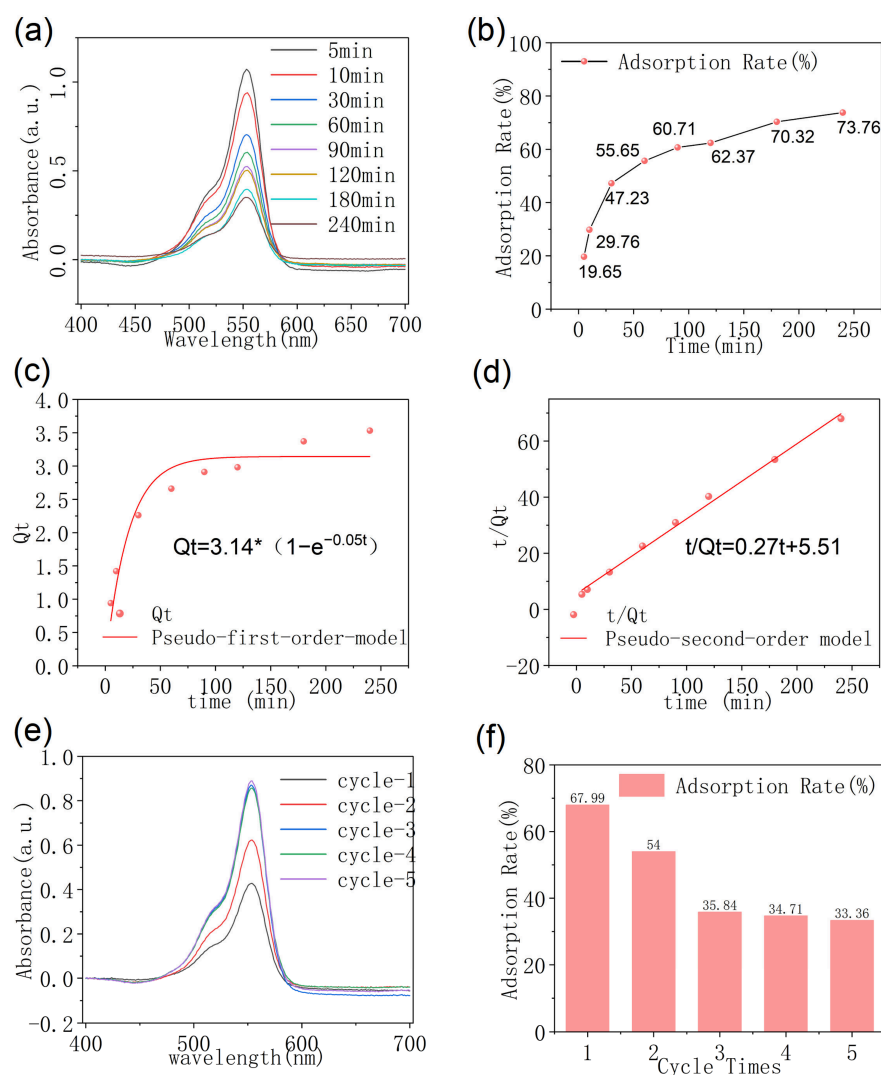


Figure 5. (a) Ultraviolet–visible spectroscopic images of PAN@COF-H yarn adsorbing rhodamine B dye; (b) adsorption rates of rhodamine B dye on PAN@COF-H yarn at different adsorption times; (c) quasi-first-order kinetic simulation and (d) quasi-second-order kinetic simulation of rhodamine B dye adsorption on PAN@COF-H yarn; (e) ultraviolet–visible spectra and (f) adsorption rate results from five cyclic adsorption experiments on PAN@COF-H yarn.

Furthermore, the mechanical robustness imparted by the oriented PAN core proved vital for practical applications. With a tensile strength of 10 MPa, the composite yarn outperforms isotropic electrospun membranes and brittle COF monoliths. This structural integrity enabled the material to withstand repeated handling during the five-cycle adsorption-regeneration tests. While a gradual decrease in adsorption capacity was observed (retaining 33.26% after five cycles, Figure 5f), this is a common phenomenon in COF-based adsorbents, likely stemming from the irreversible occupation of micropores or minor structural swelling during the ethanol regeneration process.

4. Discussion

This work presents a conjugated electrospinning strategy combined with in situ solvothermal synthesis to transform brittle covalent organic framework (COF) powders into

continuous, weavable composite yarns. The core advantage of this design lies in the synergy between the structural orientation, interfacial adhesion, and intrinsic porosity [52–55].

The axially aligned PAN nanofiber core provides robust mechanical support, endowing the composite yarn with a tensile strength of 10 MPa. This represents a significant improvement over conventional isotropic electrospun COF membranes, addressing the inherent fragility of COF materials [56–58]. The in situ growth approach ensures a uniform and conformal COF-H coating, which preserves the characteristic crystallinity and microporous architecture (94.9 m²/g BET surface area) essential for adsorption.

The pristine PAN substrate exhibits negligible BET surface area and shows no obvious microporous feature, confirming its non-porous property. A narrow pore size distribution centered at ~1.1–1.3 nm is observed for PAN@COF-H, consistent with pure COF-H, demonstrating that the in situ growth of COF-H on PAN fibers successfully maintains the intrinsic pore structure of COF-H without pore structure destruction from PAN matrix.

BET analysis confirms the presence of well-defined micropores (1.1–1.3 nm), suggesting that pore-filling effects contribute to the physical confinement of RhB molecules within the COF-H channels. XRD patterns reveal that the characteristic diffraction peaks of COF-H remain intact after adsorption, indicating that the crystalline framework is structurally stable and serves as a robust scaffold for adsorption. FT-IR spectra show a slight shift of the C=N stretching vibration (from 1570 to 1567 cm^{−1}) and the emergence of RhB-specific bands, implying electronic interactions such as π – π stacking and electron donor–acceptor (EDA) forces between the aromatic skeletons of COF-H and RhB molecules. Furthermore, kinetic modeling (pseudo-second-order) suggests that the adsorption rate is highly dependent on the availability of active sites. Collectively, these findings demonstrate that the adsorption of RhB onto PAN@COF-H is not dominated by a single interaction, but rather a synergistic process involving pore-filling, π – π stacking/EDA interactions, and electrostatic effects arising from the electron-rich nature of the COF-H framework. This multi-mechanistic mode provides a comprehensive understanding of the adsorption behavior [59–62].

The adsorption of Rhodamine B (RhB) is partly governed by chemisorption, specifically π – π stacking interactions between the aromatic frameworks of COF-H and the dye molecules, as supported by the pseudo-second-order kinetic model. The superhydrophilic nature of the yarn facilitates rapid water permeation, achieving a 73.76% removal rate within 4 h. Although the adsorption capacity retention was 33.36% after five cycles, the structural integrity of the oriented yarn remained intact, demonstrating its potential for practical handling.

Compared to traditional COF composites, this “weave-first-functionalize-later” strategy bridges the gap between microscopic crystalline frameworks and macroscopic textile architectures, offering a versatile platform for deployable environmental remediation technologies.

5. Conclusions

In summary, we have developed a novel, weavable PAN@COF-H composite yarn that effectively integrates the high porosity of COFs with the mechanical resilience of electrospun nanofibers. The “weave-first-functionalize-later” strategy ensures that the resulting material maintains excellent flexibility and tensile strength (10 MPa) while exhibiting a superhydrophilic surface and a well-defined microporous structure. Application tests demonstrated that the composite yarn achieves rapid adsorption of RhB, driven by π – π interactions and pore-filling effects. Although cycling stability requires further optimization, the material retains a considerable portion of its adsorption capacity over multiple uses, achieving a 73.76% removal rate for RhB within 4 h. This work provides a versatile platform for transforming intractable COF powders into robust, processable textiles, paving

the way for their deployment in wearable environmental remediation technologies and portable water purification systems.

Author Contributions: Conceptualization, Y.S.; methodology, F.G.; validation, W.D., Y.W. (Yaqing Wang), Y.W. (Yuanyuan Wu) and F.G.; data curation, J.L.; writing—original draft preparation, Y.S.; writing—review and editing, B.S., J.Z. and Y.C.; funding acquisition, B.S. and Y.S. All authors have read and agreed to the published version of the manuscript.

Funding: This work is supported by Joint fund project of the National Natural Science Foundation of China (U25B20174), Qingdao Natural Science Foundation (24-4-4-zrjj-61-jch), The Shandong Provincial Universities Youth Innovation Technology Plan Innovation Team (2023KJ360).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

COFs	Covalent Organic Frameworks
RhB	Rhodamine B
TFP	1,3,5-Triformylphloroglucinol
Pa-H	p-phenylenediamine

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