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Interfacial mechanism of sulfonic acid-doped polyaniline/ cotton fabric for maximized electrical properties and tailored surface functionality

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Abstract
Wearable electronics are being revolutionized by conductive polymers like polyaniline (PANI) due to their excellent optical and electrical properties. However, its processability, solvent selection, and establishment of stable synthesis protocols have hindered its widespread applications. This study aims to investigate PANI polymerization on cotton fabrics using p-toluene sulfonic acid (pTSA) as a dopant, aniline as a monomer, and ammonium persulfate (APS) as an oxidant. This research elucidates the interfacial mechanism and formulates a relationship among synthesis parameters governing electrical properties for high-performance e-textile applications. The significance lies in developing a robust strategy to conformally coat flexible cotton with highly conductive PANI for next-generation wearable devices. A Box-Behnken response surface methodology systematically optimized critical parameters - aniline monomer, oxidant, and pTSA dopant concentrations. Comprehensive characterizations were performed, including FTIR, FESEM, EDX, XRD, UV–Vis, and measurement of sheet resistance. The quadratic model fitted the data excellently (R2 = 0.9899, F = 75.95, p < 0.0001), validating the optimization approach. The optimized conditions (0.3 M aniline, 0.38 M APS, 0.6 M pTSA) facilitated a uniform PANI coating with the desirable emeraldine salt oxidation state, minimizing the sheet resistance to 2.60 kΩ/sq. This 80 % reduction compared to non-optimized syntheses dramatically enhanced charge transport within the conductive fabrics. In conclusion, this rational design strategy successfully tailored the sulfonic acid-PANI synthesis to maximize the electrical performance of cotton-based e-textiles. The optimized composites are promising for flexible energy storage, sensors, electromagnetic shielding, electro-thermal devices, and other wearable applications. Further work explores innovative PANI nanostructures and industrial scale-up feasibility. © 2025 Elsevier B.V.

Author Keywords
Aniline; APS; Cotton fabric; Polyaniline; Ptsa; Sheet resistance

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References

- Lee, J., Cho, K., Kim, J.
  Age of Flexible Electronics: emerging Trends in Soft Multifunctional Sensors
  (2024) *Adv. Mater.*, 36 (16).
- Kazanskiy, N.L., Khonina, S.N., Butt, M.A.
  A review on flexible wearables – Recent developments in non-invasive continuous

health monitoring
(2024) *Sensors Actuators A Phys.*, 366.

- Naghdi, S., Rhee, K., Hui, D., Park, S.
A Review of Conductive Metal Nanomaterials as Conductive, Transparent, and Flexible Coatings, Thin Films, and Conductive Fillers: different Deposition Methods and Applications
(2018) *Coatings*, 8 (8), p. 278.

- Liang, F., Tee, B.C.K.
Functional Liquid Metal Polymeric Composites: fundamentals and Applications in Soft Wearable Electronics
(2024) *Adv. Funct. Mater.*,

- Wang, D., Zhang, Y., Lu, X., Ma, Z., Xie, C., Zheng, Z.
Chemical formation of soft metal electrodes for flexible and wearable electronics
(2018) *Chem. Soc. Rev.*, 47 (12), pp. 4611-4641.

- Ometov, A.
A Survey on Wearable Technology: history, State-of-the-Art and Current Challenges
(2021) *Comput. Networks*, 193.

- Barakzehi, M., Montazer, M., Sharif, F., Norby, T., Chatzitakis, A.
A textile-based wearable supercapacitor using reduced graphene oxide/polypyrrole composite
(2019) *Electrochim. Acta*, 305, pp. 187-196.

- Xiong, J., Chen, J., Lee, P.S.
Functional Fibers and Fabrics for Soft Robotics, Wearables, and Human–Robot Interface
(2021) *Adv. Mater.*, 33 (19).

- Tseghai, G.B., Mengistie, D.A., Malengier, B., Fante, K.A., Van Langenhove, L.
PEDOT:pSS-Based Conductive Textiles and Their Applications
(2020) *Sensors*, 20 (7), p. 1881.

- Stejskal, J.
Conducting polymers are not just conducting: a perspective for emerging technology
(2020) *Polym. Int.*, 69 (8), pp. 662-664.

- Maity, S., Chatterjee, A.
Conductive polymer-based electro-conductive textile composites for electromagnetic interference shielding: a review
(2018) *J. Ind. Text.*, 47 (8), pp. 2228-2252.

- Bubniene, U.S., Ratautaite, V., Ramanavicius, A., Bucinskas, V.
Conducting Polymers for the Design of Tactile Sensors
(2022) *Polymers. (Basel)*, 14 (15), p. 2984.

- Ding, H.
Conducting polymers in industry: a comprehensive review on the characterization, synthesis and application
(2024) *Alexandria Eng. J.*, 88, pp. 253-267.

- Nasajpour-Esfahani, N.
A critical review on intrinsic conducting polymers and their applications
(2023) *J. Ind. Eng. Chem.*, 125, pp. 14-37.

- Omar, S.N.I.
Electrically conductive fabric coated with polyaniline: physicochemical

characterisation and antibacterial assessment
(2020) *Emergent. Mater.*, 3 (4), pp. 469-477.

- He, M., Tang, J., Wang, Y., Huang, L., Wang, X., Yu, J.
Controlled growth of polyaniline nanofibers on the surface of alkali pre-treated PI fabric as electromagnetic wave-absorbing fabrics
(2024) *Surf. Interfaces.*, 48.

- Grancarić, A.M.
Conductive polymers for smart textile applications
(2018) *J. Ind. Text.*, 48 (3), pp. 612-642.

- Harito, C.
Review—The Development of Wearable Polymer-Based Sensors: perspectives
(2020) *J. Electrochem. Soc.*, 167 (3).

- Hong, X.
Washable and Multifunctional Electronic Textiles Via In Situ Lamination for Personal Health Care
(2024) *Adv. Fiber Mater.*, 6 (2), pp. 458-472.

- Huang, J., Liu, X., Du, Y.
Highly efficient and wearable thermoelectric composites based on carbon nanotube film/polyaniline
(2024) *J. Mater.*, 10 (1), pp. 173-178.

- Li, S.
Bifunctional polyaniline electroconductive hydrogels with applications in supercapacitor and wearable strain sensors
(2020) *J. Biomater. Sci. Polym. Ed.*, 31 (7), pp. 938-953.

- Bao, X., Meng, J., Tan, Z., Zhang, C., Li, L., Liu, T.
Direct-ink-write 3D printing of highly-stretchable polyaniline gel with hierarchical conducting network for customized wearable strain sensors
(2024) *Chem. Eng. J.*, 491.

- Sharma, N., Singh, A., Kumar, N., Tiwari, A., Lal, M., Arya, S.
A review on polyaniline and its composites: from synthesis to properties and progressive applications
(2024) *J. Mater. Sci.*, 59 (15), pp. 6206-6244.

- Das, D., Das, J., Debnath, A., Chakraborty, S., Saha, B.
Polyaniline-graphite on cellulose substrate: a flexible, low-cost, use-and-throw sensor for glucose concentration detection
(2023) *Cellulose*, 30 (10), pp. 6423-6433.

- Aizamddin, M.F., Mahat, M.M., Nawawi, M.A.
A straightforward approach of chemical oxidative polymerization to synthesis polyaniline for the conductive fabrics applications
(2024), p. 040043.

- Sandhu, Z.A.
Response surface methodology: a powerful tool for optimizing the synthesis of metal sulfide nanoparticles for dye degradation
(2023) *Mater. Adv.*, 4 (21), pp. 5094-5125.

- Whitcomb, P.J.
RSM Simplified
(2004), Productivity Press

- Veza, I., Spraggon, M., Fattah, I.M.R., Idris, M.
Response surface methodology (RSM) for optimizing engine performance and emissions fueled with biofuel: review of RSM for sustainability energy transition
(2023) *Results. Eng.*, 18.

- Sakthivel, S., Boopathi, A.
Characterization study of Electrically Conductive PANI Coated Cotton Textile Fabric
(2015), 5, pp. 111-116.
no. March

- Patil, A.J., Deogaonkar, S.C.
A novel method of in situ chemical polymerization of polyaniline for synthesis of electrically conductive cotton fabrics
(2012) *Text. Res. J.*, 82 (15), pp. 1517-1530.

- Raditoiu, A.
Coloured silica hybrids for functionalizing cellulose materials
(2012) *J. Optoelectron. Adv. Mater.*, 14, pp. 846-851.

- Tissera, N.D., Wijesena, R.N., Rathnayake, S., de Silva, R.M., de Silva, K.M.N.
Heterogeneous in situ polymerization of polyaniline (PANI) nanofibers on cotton textiles: improved electrical conductivity, electrical switching, and tuning properties
(2018) *Carbohydr. Polym.*, 186, pp. 35-44.

- Zhou, Z., Sun, J.
Fabrication and Characterization of Polyaniline on Cotton Fabric via Two-Step in-situ Polymerization
(2021) *J. Phys. Conf. Ser.*, 1790 (1).

- Dudem, B., Mule, A.R., Patnam, H.R., Yu, J.S.
Wearable and durable triboelectric nanogenerators via polyaniline coated cotton textiles as a movement sensor and self-powered system
(2019) *Nano Energy*, 55, pp. 305-315.

- Goswami, S., Nandy, S., Fortunato, E., Martins, R.
Polyaniline and its composites engineering: a class of multifunctional smart energy materials
(2023) *J. Solid State Chem.*, 317.

- Singh, P., Shukla, S.K.
Advances in polyaniline-based nanocomposites
(2020) *J. Mater. Sci.*, 55 (4), pp. 1331-1365.

- Ding, R., Meng, Y., Qiao, Y., Wu, M., Ma, H., Zhang, B.
Functionalizing cotton fabric via covalently grafting polyaniline for solar-driven interfacial evaporation of brine
(2022) *Appl. Surf. Sci.*, 598.

- Teklu, T.
Polyaniline Deposition on the Surface of Cotton Fibers: structural Studies, Swelling Behavior, and Water Absorption Properties
(2020) *Adv. Mater. Sci. Eng.*, 2020, pp. 1-8.

- Banerjee, J., Dutta, K., Kader, M.A., Nayak, S.K.
An overview on the recent developments in polyaniline-based supercapacitors
(2019) *Polym. Adv. Technol.*, 30 (8), pp. 1902-1921.

- Beygisangchin, M., Rashid, S.A., Shafie, S., Sadrolhosseini, A.R., Lim, H.N.
Preparations, Properties, and Applications of Polyaniline and Polyaniline Thin Films—A Review
(2021) *Polymers. (Basel)*, 13 (12), p. 2003.

- Wong, P.-Y., Phang, S.-W., Baharum, A.
Effects of synthesised polyaniline (PAni) contents on the anti-static properties of PAni-based polylactic acid (PLA) films
(2020) *RSC. Adv.*, 10 (65), pp. 39693-39699.

- Beygisangchin, M., Hossein Baghdadi, A., Kartom Kamarudin, S., Abdul Rashid, S., Jakmunee, J., Shaari, N.
Recent progress in polyaniline and its composites; Synthesis, properties, and applications
(2024) *Eur. Polym. J.*, 210.

- Deb, K., Bera, A., Saha, B.
Tuning of electrical and optical properties of polyaniline incorporated functional paper for flexible circuits through oxidative chemical polymerization
(2016) *RSC. Adv.*, 6 (97), pp. 94795-94802.

- Rahman, M.M., Joy, P.M., Uddin, M.N., Bin Mukhlish, M.Z., Khan, M.M.R.
Improvement of capacitive performance of polyaniline based hybrid supercapacitor
(2021) *Heliyon.*, 7 (7).

- Kim, H., Yi, J.-Y., Kim, B.-G., Song, J.E., Jeong, H.-J., Kim, H.R.
Development of cellulose-based conductive fabrics with electrical conductivity and flexibility
(2020) *PLoS. One*, 15 (6).

- Prasher, S., Kumar, M., Kaur, U., Tyagi, S.
Synthesis and characterization of polyaniline-nickel chloride composites
(2020) *J. Phys. Conf. Ser.*, 1531 (1).

- Pattanarat, K., Petchsang, N., Osotchan, T., Tang, I.-M., Kim, Y.-H., Jaisutti, R.
High conductivity and durability textile gas sensor-based polyaniline-decorated-poly(3,4-ethylenedioxythiophene)/poly(4-styrenesulfonate) for ammonia detection
(2022) *ACS Appl. Polym. Mater.*, 4 (12), pp. 9006-9014.

- Butoi, B., Groza, A., Dinca, P., Balan, A., Barna, V.
Morphological and structural analysis of polyaniline and poly(o-anisidine) layers generated in a DC glow discharge plasma by using an oblique angle electrode deposition configuration
(2017) *Polymers. (Basel)*, 9 (12), p. 732.

- Shateri-Khalilabad, M., Yazdanshenas, M.E., Etemadifar, A.
Fabricating multifunctional silver nanoparticles-coated cotton fabric
(2017) *Arab. J. Chem.*, 10, pp. S2355-S2362.

- Bhat, N.V., Seshadri, D.T., Radhakrishnan, S.
Preparation, characterization, and performance of conductive fabrics: cotton + PANi
(2004) *Text. Res. J.*, 74 (2), pp. 155-166.

- Golba, S.
Impact of acidity profile on nascent polyaniline in the modified rapid mixing process—material electrical conductivity and morphological study
(2020) *Materials. (Basel)*, 13 (22), p. 5108.

- Tadesse, M.G., Mengistie, D.A., Chen, Y., Wang, L., Loghin, C., Nierstrasz, V.
Electrically conductive highly elastic polyamide/lycra fabric treated with PEDOT:PSS and polyurethane
(2019) *J. Mater. Sci.*, 54 (13), pp. 9591-9602.

- Onar, N., Akşit, A.C., Ebeoglugil, M.F., Birlik, I., Celik, E., Ozdemir, I.
Structural, electrical, and electromagnetic properties of cotton fabrics coated with

polyaniline and polypyrrole
(2009) *J. Appl. Polym. Sci.*, 114 (4), pp. 2003-2010.

- Parvez, M.S., Rahman, M.M., Samykano, M., Ali, M.Y.
Electrochemical characterization and joule heating performance of polyaniline incorporated cotton fabric
(2023) *Phys. Chem. Earth, Parts A/B/C*, 129.

- Abel, S.B., Frontera, E., Acevedo, D., Barbero, C.A.
Functionalization of Conductive Polymers through Covalent Postmodification
(2022) *Polymers. (Basel)*, 15 (1), p. 205.

- Ibrahim, K.A.
Synthesis and characterization of polyaniline and poly(aniline-co-o-nitroaniline) using vibrational spectroscopy
(2017) *Arab. J. Chem.*, 10, pp. S2668-S2674.

- Bhadra, J., Al-Thani, N.J., Madi, N.K., Al-Maadeed, M.A.
Effects of aniline concentrations on the electrical and mechanical properties of polyaniline polyvinyl alcohol blends
(2017) *Arab. J. Chem.*, 10 (5), pp. 664-672.

- Abd Rahim, S.H., Zainol, N., Samad, K.A.
Optimization of chlorophyll extraction from pineapple plantation waste
(2022) *Heliyon.*, 8 (11).

- Shari, H., Majid, S., Ghorbani, M.
The application of response surface methodology on the synthesis of conductive polyaniline /cellulosic fi ber nanocomposites
, 194, pp. 384-394.
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