Dhaka University Nanotechnology Center (DUNC)
University of Dhaka
Dhaka-1000, Bangladesh

Inception Report 2025-26

1. Summary of the proposal (Max 200 words: Proposal at a glance):

This research proposal addresses the critical transition from rigid electronics to flexible, multifunctional smart textiles by systematically developing graphene-based conductive textiles with tailored electrical and mechanical properties. While traditional metals offer high conductivity, their stiffness and susceptibility to corrosion limit their practical use in wearable technology. Consequently, this study explores graphene and its derivatives, like graphene oxide (GO) and reduced graphene oxide (rGO), as superior alternatives due to their mechanical strength and dispersibility. The project aims to bridge a significant research gap by investigating the molecular-level chemistry of hybrid systems where graphene acts as the primary matrix rather than just a filler. This research intends to develop available and affordable conductive fabrics through the systematic optimization of matrix-filler proportions and the synthesis of graphene-based composites. By utilizing advanced characterization techniques, the study will elucidate the structure-property relationships necessary to fine-tune electrical performance. Ultimately, this work seeks to provide detailed insights into interfacial chemistry, enabling the creation of smart textile prototypes that offer robust stability and flexibility for next-generation applications contributing significantly to the global demand for sustäinable, green technology solutions.

2. Introduction:

Smart textiles represent an advanced class of technology which merge traditional fabrics with advanced functional elements, integrating ability of sensing, actuation and enabling responsive interactions with mechanical, electrical, or environmental stimuli. This class of advanced textile materials have gained notable scientific interest due to their wide range of applications such as biomedical devices, sensors, actuators, storage devices, and communication devices [1]. Central to this innovation is the integration of conductive materials into textile fibres, which offers unprecedented opportunities for flexibility and multifunctionality in wearable devices previously reserved for rigid electronics. Conventional textile materials are usually insulating materials, where they cannot be used directly for smart textile applications that require electrical conductivity. It is possible to obtain electrically conductive textile by integrating metallic wires, conductive polymers, or other conductive compounds into the textile structure at different stages, such as fiber construction, yarn spinning, or fabric creation stages [2]. By incorporating conductive nanofillers which create percolated networks for charge transport, these systems overcome the inherent electrical insulation of natural fibers like cotton [3]. While metals offer unbeatable electrical conductivity, metal-based e-textiles are usually stiff, heavy, highly corrosive, environmentally unstable, and expensive. These limitations are the primary driving force for exploring alternative conductive materials- such as conducting polymers (CPs), graphene, carbon nanotubes (CNTs) and a variety of hybrid approaches.

Graphene, due to its exceptional electrical conductivity and mechanical strength, is emerging as a prime candidate to form the basis of a conductive matrix and has been incorporated into different polymeric materials. single-layer sp^2-hybridized carbon lattice delivers exceptional carrier mobility and high surface area, forming continuous conductive pathways when coated onto textiles via dip-coating or printing [4]. However, the poor production of coatings by graphene on common textiles leads to graphene oxide (GO) as an alternative because it exhibits superior dispersibility in polar and hydrophilic solvents, allowing uniform matrix formation on cotton yarns, though subsequent reduction is necessary for recovering the electrical conductivity. For example, Javed et al. reported reduced graphene oxide (rGO) on the surfaces of wool and cotton fibers to create electrically conductive networks [5]. Yun et al. reported rGO/cotton yarns to enhance flexibility and electromechanical stability [6]. Cheng et al. developed a graphene-based fiber for sensing tensile strain, bending, and torsion [7].

Conducting polymers and carbon nanotubes, alongside with metal oxide nanoparticles pose as ideal candidates for conductive textiles because of their good electrical conductivity, mechanical properties and electrochemical activities. When used as conductive fillers with graphene-based matrices the materials should exhibit synergistic effects, and the resulting composite systems can be finely tuned to meet the demanding performance criteria of smart textile applications. Yoon et al. reported graphene/Ag hybrid fiber with excellent conductivity [9]. Zhang et al. fabricated graphene/SWCNT having satisfactory electrical conductance and better surface morphology [9]. Similarly, many graphene-polymer composites have been reported to show significantly high conductivity. Conducting polymers like polyaniline (PAni), poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS), and polypyrrole (PPy) conduct via doped charge defects, polarons and bipolarons, that propagate along conjugated backbones, achieving conductivities up to 300 S/cm post-doping [10]. While there are numerous studies on graphene as a filler component in different polymer, there is lack of investigation on conductive systems with graphene-based matrices. The fundamental chemistry governing these hybrid systems remains unexplored at the molecular level as well. A systematic study of these interactions is critical to design textiles with tailored properties for specific applications and enable next generation applications. This research aims to bridge this gap by developing graphene-based conductive textiles and elucidating the structure-property relationships governing their performance.

3. Background of the Research:

Graphene and its derivatives GO and rGO are emerging as promising materials which can be introduced into insulating textiles to transform them into conductive channels via various fabrication procedures. Zhang et al. designed a dual-shell interafcial structure on cotton yarns using rGO inner layers for adhesion and graphene outer shells, achieving conductivities up to 5×10^3 S·m^{-1} with 21-fold tensile strength gains [3]. rGO-coated nylon and cotton have been reported to yield sheet resistances of 350 Ω/sq and 1 kΩ/sq respectively after hydrazine reduction, retaining stability over 40 wash cycles with binders like bovine serum albumin. Dispersibility of GO supports scalable dip-coating, enhancing bending resistance and enabling sensors for heart rate with 66 to 90 bpm accuracy [11]. Many conducting polymers like PAni, PEDOT:PSS, and PPy provide lightweight conductivity without rigidifying fabrics. PEDOT:PSS on Spandex reaches 1.71 S/cm via repeated immersion with sorbitol, increasing under stretch due to particle alignment [10]. Jalili et al. reported a wet-spun PEDOT:PSS-PEG electroconductive fiber that achieved 264 S/cm, supporting electromagnetic interference (EMI) shielding and supercapacitors [12]. Sheibani et al. carried out PAni in situ polymerization on cotton, doped with HCl and oxidized by APS, and reported that resistivity can be tuned via monomer ratios, offering flexibility and sensing [13].

GO/PAni hybrids systems leverage the GO matrix for uniform PAni nanofiller dispersion, enhancing conductivity through polaron hopping and π-π stacking. Fang et al. investigated a synchronous mechanochemical synthesis which stabilizes graphene via π-π conjugation while in situ PAni polymerization yields stretchable composites for energy textiles [14]. These show two orders of magnitude conductivity gains in electro-spun nanofibers versus PAni alone, with strong interphase bonding preventing delamination. rGO/PAni blends exhibit improved electrochemical stability for supercapacitor [15]. GO-PAni composites coat cotton for strain sensors and Joule heaters, with PAni filler reducing resistance under deformation via charge defect mobility. Gan et al. wet-coated graphene nanoribbons on cotton, boosting conductivity and durability over 200 bends [16]. HCl-doped PAni on cotton enhances resistivity control, ideal for GO matrix approach [13]. Composites have been reported to retain >80% conductivity post-washing, outperforming metal coatings in comfort and flexibility [11].

4. Research Questions and Objectives:

Ever since the advent of smart textiles, growing interest and research continue on graphene-based hybrid systems due to their prospects in wearable electronics, sensors, and energy storage devices. While studies on conductive textiles have mostly focused on graphene or conducting polymers as individual fillers, few reports have truly explored graphene and its derivatives as a stable matrix hosting conductive polymers like polyaniline (PAni) for enhanced electroconductivity on natural fibers. However, achieving uniform dispersion, strong interfacial bonding, and sustained performance under mechanical stress remains challenging in textile substrates. Thus, developing graphene-based matrices with PAni fillers is extremely necessary; albeit this still poses a significant hurdle owing to weak π-π interactions and aggregation issues. On the contrary, very few studies have reported strategies to optimize graphene-PAni hybrids specifically for smart textile applications. Consequently, the lack of systematic investigations into molecular-level interactions and structure-property relationships limits the scalability and multifunctionality of these promising composites.

In previous reports, rGO-coated cotton yarns have shown improved flexibility and electromechanical stability, but standalone graphene coatings often suffer from poor adhesion and wash durability on insulating textiles like cotton. Similarly, PAni-coated fabrics exhibit tunable conductivity via doping, yet suffer from brittleness and environmental instability without a supportive matrix. Therefore, an obvious synergy exists between dispersibility of graphene and charge carriers of PAni, where graphene or its derivative can act as a lamellar scaffold facilitating polaron hopping across hybrid networks. To successfully harness effective control over electrical conductivity, mechanical resilience, and textile compatibility in graphene-PAni systems, a firm understanding of the correlation between synthesis parameters, filler ratios, interfacial chemistry, and macroscopic properties is therefore required. More extensive reports are needed that elucidate the precise molecular sites of π-π stacking, hydrogen bonding, and doping effects in graphene-PAni hybrids under textile-relevant conditions, considering variables like matrix-to-filler ratios, reduction methods, and fiber substrates.

The ultimate objective of this work can be expressed in three segments: (1) to optimize graphene-based hybrid systems by incorporating PAni and other conductive fillers, varying synthesis parameters to achieve high electroconductivity and uniform dispersion; (2) to investigate the molecular-level interfacial interactions governing charge transport, mechanical properties, and stability in these composites; and (3) to fabricate and evaluate smart textile prototypes using the optimized hybrids for applications in sensing and wearable devices.

5. Theoretical framework, if required: Not required

6. Analytical/Operational Framework, if required: Not required

7. Detailed Methodology:

a. Research Methods:

Graphene-based hybrid systems will be prepared following a modified Hummers' method for GO synthesis, where the concentrations of oxidizing agents ($KMnO_4$ and $NaNO_3$), reaction temperature, and ultrasonication time will be systematically varied to optimize GO sheet size, oxygen content, and colloidal stability for textile coating applications. Subsequent chemical reduction using ascorbic acid will produce rGO, with reduction time, pH, and temperature parameters adjusted to restore π-conjugation while retaining sufficient functional groups for filler anchoring. PAni will then be introduced as conductive filler via in situ polymerization of aniline monomer in the presence of HCl dopant and ammonium persulfate (APS) oxidant, systematically varying graphene-to-PAni weight ratios to study their impact on dispersion uniformity, π-π stacking, and initial conductivity.

In the second part, the composites will be coated onto cotton yarn substrates using dip-coating or spray-coating techniques, and the influence of matrix-filler interactions on charge transport and mechanical adhesion will be investigated in detail, with coating cycles (1–10 dips) and drying conditions varied to achieve percolated networks. The interfacial chemistry, such as hydrogen bonding between functional groups of graphene-based matrix and amine sites of PAni, will be probed through systematic variation of doping levels, enabling elucidation of how these parameters govern polaron hopping efficiency and strain tolerance in textile-bound composites.

For the third part, prior to smart textile prototyping, optimized graphene-PAni hybrids will be electrospun into nanofibers or directly woven into cotton fabrics, with post-treatments to enhance fiber adhesion and wash fastness. These prototypes will then be evaluated for electromechanical performance under cyclic bending, stretching, and laundering, quantifying conductivity retention and gauge factors for sensing applications. This will demonstrate the potential of graphene-PAni systems as viable candidates for multifunctional smart textiles, bridging molecular design with practical wearable devices for wide range of applications.

b. Data Collection Techniques: Sources of data and data collection tools and techniques:

Machine generated data will be used and analyses will be carried out following standard procedures

c. Detailed Sampling: techniques, size, area/location of data collection and nature of respondents, number of enumerators, if required: Not applicable

d. Machine, Materials and Technologies to be used (in details):

Synthesis parameters of graphene-based hybrid systems will be varied for preparation of conductive matrices, which are: (i) oxidizing agent concentrations, (ii) reduction agent type and dosage, and (iii) reaction conditions (temperature, ultrasonication duration) during GO exfoliation and rGO formation. Tuning such parameters will expose a clear picture of the restoration mechanism of π-conjugation and provide precise control over sheet size, oxygen functional group density, and dispersibility for optimal textile coating adhesion. This control will open more pathways towards enhanced electroconductivity and mechanical stability in smart textile applications.The responses from π-π stacking interactions between sp^2 domains of graphene-based matrix and quinoid rings of PAni, along with doping effects, will be analyzed to elucidate charge transport pathways.

The GO, rGO, PAni, and hybrid composites synthesized will be characterized by Fourier Transform Infrared (FTIR) spectroscopy for identification of functional groups (C=O, O-H, C-N) and interfacial bonding shifts, by X-ray Diffraction (XRD) analysis for crystallinity and d-spacing changes in graphene matrix sheets post-filler integration, by Raman spectroscopy for ID/IG ratio evolution indicating defect healing, and by Thermogravimetric Analysis (TGA) for thermal stability and composition quantification. Morphology, surface topography, and nanofiller dispersion will be examined by Scanning Electron Microscopy (SEM) and Atomic Force Microscopy (AFM), while X-ray Photoelectron Spectroscopy (XPS) will deconvolute C1s and N1s peaks to confirm chemical states and doping levels in the hybrids.
The composite coated cotton yarns and smart textile prototypes will be evaluated using Electrochemical Impedance Spectroscopy (EIS) for Nyquist plot analysis of charge transfer resistance and ion diffusion at percolated networks, and Cyclic Voltammetry (CV) for pseudocapacitive behavior and specific capacitance under varying scan rates. Mechanical-electrical coupling will be assessed via four-point probe conductivity measurements before and after bending cycles, alongside tensile testing for Young's modulus and elongation retention. Wash fastness and environmental stability will be quantified post-laundering using standardized AATCC protocols, with UV-Vis spectroscopy tracking filler leaching. These comprehensive characterizations will validate the potential of the hybrids for scalable, multifunctional smart textiles.

8. Data Analysis Mechanism:

Data will be analyzed systematically and compared with the standard values available in literature.

9. Expected Output and Outcome:

Major applications of graphene-based hybrids in smart textiles demand uniform conductive networks with tunable electroconductivity, mechanical flexibility, and laundering durability. Thus, a well-established understanding of molecular interactions in graphene-PAni systems will prove extraordinarily beneficial for tailoring filler-matrix ratios and synthesis conditions. Proposed work will also unfold strategies to regulate composite morphology and interfacial bonding, which is crucial since wearable applications require specific hierarchical structures (percolated pathways, nanofiber integration, yarn coating uniformity). Another prospect of such systems lies in multifunctional sensing platforms, where optimized graphene-based matrix hosting PAni fillers promise robust strain and humidity response. Developing these hybrids with enhanced π-π stacking and doping efficiency, as proposed here, will result in conductive textiles with well-controlled sheet resistance, stretchability, and wash fastness, expected to outperform conventional metal-coated fabrics in comfort and scalability.

Smart textiles integrated with graphene-based composites address critical gaps in wearable electronics, where inherent insulation of cotton yarns limits health monitoring, thermotherapy, and energy harvesting capabilities. Conventional approaches suffer from poor adhesion, environmental instability, and high production costs, hindering commercialization in resource-constrained settings like Bangladesh. Therefore, systematic optimization of these hybrids offers a cost-effective pathway to bridge rigid electronics with flexible fabrics. This work proposes such advancements by elucidating structure-property relationships, enabling prototypes that maintain significant conductivity post-cyclic deformation while preserving breathability and biocompatibility essential for prolonged wear.

10. Organization of the Final Report/Tentative Chapters:

The final report will be consisted of the following Chapters in the following order,

1. Abstract/Summary
2. Introduction
3. Background/Literature Review
4. Materials and Methods
5. Results and Discussion
6. Conclusions
7. References
8. Acknowledgement

11. Detailed Budget as Per Allocation:

(a) Research Fellowship: 12,000×5=60,000 TK
(b) Equipment:
(c) Other Accessories/Chemicals:
(d) Contingency: 3,000 TK
(e) Analytical Services:
Total: 63,000 TK

12. Timeframe of the Research (Gantt Chart):

The research has been initiated as a part of MS thesis in the physical chemistry research laboratory of Department of Chemistry at University of Dhaka. The research will be completed within the 2025-26 academic year.

13. Limitations of the Study:

Doing quality research in Bangladesh on graphene-based hybrid systems for smart textiles is often constrained by limited access to advanced instrumentation, inadequate maintenance infrastructure, and insufficient funding for high-resolution nanoscale analysis. This study focuses on graphene-polymer composites and their textile integration, where atomic-level insights into π-π stacking and nanofiller dispersion are crucial. Transmission Electron Microscopy (TEM) is essential for visualizing sheet interlayer spacing of the graphene-based matrix and PAni uniformity within the matrix, yet TEM facilities remain unavailable across major institutions including Dhaka University. Reputed journals in materials science and nanotechnology frequently mandate TEM images for composite morphology validation, potentially hindering publication of this work without external collaborations. As the premier research hub in Bangladesh, Dhaka University should prioritize TEM acquisition, alongside training skilled operators, to empower local researchers in smart textile nanotechnology.

Furthermore, other essential tools like FTIR, XRD, and SEM while available, these face operational limitations that impact comprehensive characterization of the hybrid conductivity mechanisms. The available XRD instrument lacks low-angle detection capabilities critical for resolving graphene matrix d-spacing and interlayer expansion upon PAni doping, restricting precise structural analysis of the conductive matrix. Similarly, while SEM provides surface morphology of coated cotton yarns, the absence of high-vacuum Field Emission SEM (FESEM) limits resolution below 10 nm, impeding observation of nanofiller percolation networks under strain. Electrochemical workstations for EIS and CV are often cannot handle low-impedance textile electrodes, compromising accurate measurement of charge transfer kinetics in prototypes.

14. Stakeholders Related to This Study and Expected Beneficiaries:

This proposed work holds significant potential through its contributions in both fundamental science and applied technology. By systematically analyzing the structure–property relationships of graphene-based composites, this work contributes to a deeper molecular-level comprehension of charge transport mechanisms and interfacial compatibility. These insights can serve as a foundation for designing and screening of new hybrid materials for multifunctional smart textiles.

The hybrid systems studied here can leave impression due to its numerous beneficiary properties in the production of smart garments for real-time health monitoring, motion tracking, or temperature regulation. The incorporation of such systems into yarns and fabrics will introduce new manufacturing pathways for e-textiles. As the demand for sustainable, multifunctional materials rises, this research aligns with global efforts toward smarter, greener, and more inclusive technology solutions.

This research stands at the intersection of nanotechnology, materials science, and textile engineering, offering a rich ground for innovation. By systematically analyzing the structure–property relationships of graphene-based composites, the study can create a framework for exploring other nanomaterial combinations, opening the door to the discovery of novel materials with tailored electrical, mechanical, and functional characteristics. Such foundational research will reveal new possibilities for scientists and researchers and guide them for future interdisciplinary projects in nanomaterials, biotechnology, and electronic engineering as well, who are also potential beneficiaries.

Since an M.S. student will be associated with the project, the implementation of this project would train the student with advanced aspects of science without requiring additional manpower. The project would help to build up knowledge base in such an important area of science. The objective of building up capacity for carrying research may thus be realized.

15. Acknowledgment:

This work has been funded by Dhaka University Nanotechnology Centre (DUNC), University of Dhaka.

16. References:

1. Dutta, S., Mehraeen, S., Martinez, J. G., Bashir, T., Persson, N. K., & Jager, E. W. Textile Actuators Comprising Reduced Graphene Oxide as the Current Collector. *Macromolecular Materials and Engineering.* 2024, 309(3), 2300318.
2. Tseghai, G. B., Malengier, B., Fante, K. A., Nigusse, A. B., & Van Langenhove, L. Integration of conductive materials with textile structures, an overview. *Sensors.* 2020, 20(23), 6910.
3. Zhang, Y., Chen, X., Chen, H., Jia, M., Cai, H., Mao, Z., & Bai, Y. Developing a highly-conductive and strength cotton yarn through dual shell architecture of graphene for smart wearable devices. *Chemical Engineering Journal.* 2023, 470, 143912.
4. Aznar, P. R. D., & Junior, H. L. O. Advances and Applications of Graphene-Enhanced Textiles: A 10-Year Review of Functionalization Strategies and Smart Fabric Technologies. *Textiles.* 2025, 5(3), 28.
5. Javed, K., Galib, C. M. A., Yang, F., Chen, C. M., & Wang, C. A new approach to fabricate graphene electro-conductive networks on natural fibers by ultraviolet curing method. *Synthetic Metals.* 2014, 193, 41-47.
6. Yun, Y. J., Lee, H. J., Son, T. H., Son, H., & Jun, Y. Mercerization to enhance flexibility and electromechanical stability of reduced graphene oxide cotton yarns. *Composites Science and Technology.* 2019, 184, 107845.

7. Cheng, Y., Wang, R., Sun, J., & Gao, L. A stretchable and highly sensitive graphene-based fiber for sensing tensile strain, bending, and torsion. *Advanced Materials,* 2015, 27(45), 7365-7371.
8. Yoon, S. S., Lee, K. E., Cha, H. J., Seong, D. G., Um, M. K., Byun, J. H., Oh, Y., Oh, J.H., Lee, W. & Lee, J. U. (2015). Highly conductive graphene/Ag hybrid fibers for flexible fiber-type transistors. S*cientific Reports.* 2015, 5(1), 16366.
9. Zhang, J., Chen, Z., Xu, X., Liao, W., & Yang, L. A simple and efficient approach to fabricate graphene/CNT hybrid transparent conductive films. *RSC Advances.* 2017, 7(83), 52555-52560.
10. Alhashmi Alamer, F., Althagafy, K., Alsalmi, O., Aldeih, A., Alotaiby, H., Althebaiti, M., Alghamdi, H., Alotibi, N., Saeedi, A., Zabarmawi, Y. and Hawsawi, M. & Alnefaie, M. A. Review on PEDOT: PSS-based conductive fabric. *ACS omega.* 2022, 7(40), 35371-35386.
11. Nikolaev, D. V., Evseev, Z. I., Smagulova, S. A., & Antonova, I. V. Electrical properties of textiles treated with graphene oxide suspension. *Materials.* 2021, 14(8), 1999.
12. Grancarić, A. M., Jerković, I., Koncar, V., Cochrane, C., Kelly, F. M., Soulat, D., & Legrand, X. Conductive polymers for smart textile applications. *Journal of Industrial Textiles.* 2018, 48(3), 612-642.
13. Abilevitch, L., Mizrahi, L., Cohen, G., Kenig, S., & Amir, E. Polyaniline for Smart Textile Applications. Trends and Developments in Modern Applications of Polyaniline. 2023.
14. Fang, Z., Tian, D., Fan, B., Zhang, Y., & Wang, K. Preparation of Graphene/Polyaniline Composites by Synchronous Mechanical Exfoliation and Their Application in Elastic Fiber Supercapacitors. *Polymer.* 2025, 128885.
15. Salavagione, H. J., Gómez-Fatou, M. A., Shuttleworth, P. S., & Ellis, G. J. New perspectives on graphene/polymer fibers and fabrics for smart textiles: the relevance of the polymer/graphene interphase. *Frontiers in Materials.* 2018, 5, 18.
16. Gan, L., Shang, S., Yuen, C. W. M., & Jiang, S. X. Graphene nanoribbon coated flexible and conductive cotton fabric. *Composites Science and Technology.* 2015, *117*, 208-214.

Dr. Md. Abu Bin Hasan Susan
Professor
Department of Chemistry
University of Dhaka
Dhaka-1000, Bangladesh

17. Signature of the Principal Investigator:

Name: Professor Dr. Md. Abu Bin Hasan Susan
Signature: Dr. Md. Abu Bin Hasan Susan, Professor, Department of Chemistry, University of Dhaka, Dhaka-1000, Bangladesh Date: 15 January 2026

18. Signature of the Director of the Entity:

Name:
Signature: Prof. Dr. Md. Abu Bin Hasan Susan, Director, Dhaka University Nanotechnology Centre (DUNC), University of Dhaka, Dhaka-1000, Bangladesh Date: