Chapter 8

Summary and Conclusions

Polythiophene-multiwalled carbon nanotubes nanocomposites are remarkable in different applications due to their prominent and distinguishable properties. The conducting polythiophene and its derivatives also acquire special attention due to its electrical conductivity, optoelectronic properties, thermal properties, and biocompatibility. Polythiophene-based carbon nanocomposites are one of the most demanding research areas for conducting polymer nanocomposites. Synthetic strategies of polythiophene-carbon nanotube nanocomposites demand facile and productive approaches, which could form well-structured nanocomposites. A structure-property relationship can be fine-tuned in well-structured nanocomposites. Therefore, preparing well-structured nanocomposites to improve physical characteristics is an active area of research. In this work, a study was conducted based on synthetic approaches, characterizations and applications of conducting polythiophene-carbon nanotube nanocomposites. We could also explore and establish new application areas via its properties. **Chapter 1** deals with a literature review of polythiophene-carbon nanotube nanocomposites and also discusses the synthetic methods for polythiophene-carbon nanotube nanocomposites formation, keeping an impact on the general and specific applications based on electrical, thermal, optical, and mechanical properties**.**

In **Chapter 2**, polythiophene-carbon nanotube nanocomposites (PTCNTs) were prepared by in-situ chemical oxidative polymerization of thiophene with the assistance of sodium bis(2-ethyl hexyl) sulfosuccinate (AOT) surfactant using $FeCl_3$ as an oxidant in the presence of pristine MWCNT in chloroform. A core-shell nano-structure of the nanocomposites was evidenced in morphological analysis. The influence of surfactant AOT in the formation of core-shell morphology was recognized. Furthermore, the role of AOT as a dopant, surfactant and stabilizing agent was established. The prepared nanocomposites were also characterized by improved electrical conductivity, thermal stability and dispersibility in chloroform. In **Chapter 3**, the functionalization of carbon nanotubes was carried out by treatment with nitric acid. The functionalization of pristine MWCNT resulted in the formation of highly dispersible carbon nanotubes named as MWCNT-COOH. Functionalization of carbon nanotubes increases the processability in synthesizing their nanocomposites with conducting polythiophene, however with minimum carbon nanotube destruction. Polythiophene-functionalized carbon nanotube nanocomposites (PTCNT-COOH) were prepared by in-situ chemical oxidative polymerization of thiophene in the stable dispersion of MWCNT-COOH in chloroform using $FeCl_3$ as oxidant and with the surfactant AOT. The nanocomposites PTCNT-COOHs were characterized by core-shell morphology with a thicker outer shell of polythiophene on carbon nanotube. An enhancement in electrical conductivity and thermal stability was also obtained. The PTCNT-COOH nanocomposites exhibited stable dispersion in polar and less polar media. The dispersion stability of PTCNT-COOH and MWCNT-COOH in water is directed to the preparation of higher-order nanocomposites. In **chapter 4,** a green synthetic approach could establish to produce ternary silver nanoparticles embedded polythiophene-functionalized multiwalled carbon nanotube nanocomposites (PTCNT-COOH 300 Ag) by in-situ chemical reduction with ascorbic acid (vitamin C) in the presence of stable dispersion of binary PTCNT-COOH 300 in water. A binary silver nanocomposite MWCNT-COOH Ag was also prepared using the same synthetic approach. The ternary and binary silver nanocomposites exhibited excellent dispersion stability in various solvents, superior electrical conductivity, and high thermal stability.

In **chapter 5**, the applications of PTCNT-COOH 300 Ag (TNC) and MWCNT-COOH Ag (BNC) were established (i) as heterogeneous catalysts in nitrophenol reduction with the reductant $NaBH_4$ and (ii) as good antibacterial agents against *E. coli* bacteria. An elaborated study of catalytic nitrophenol reduction in different solvents proved that not only the reductant but also active solvent hydrogens present in solvents also influence the reduction mechanism. An industrial-scale preparation of aminophenol from nitrophenol could be demonstrated in a 10% glycerol-water mixture with a high catalyst activity factor of 936.50 s^{-1} g^{-1}. PTCNT-COOH 300 Ag (TNC) exhibited prominent antibacterial activity in a water-based nutrient broth with a low concentration of 10 µg/mL. In **Chapter 6**, the TNC and BNC as heterogeneous catalysts were used for decolourisation of water-soluble and insoluble organic azo dyes. Catalytic decolourisation of water-insoluble azo dyes was effectively carried out in the ethanol-water mixture as the medium and exhibited high rate constants. The product-selective catalytic reduction of azobenzene to hydrazobenzene was also carried out with the BNC nanocatalyst. The large-scale reduction was demonstrated within a short reaction time of 15 min with a minimum nanocatalyst (0.18 mg/mL) and reductant with azobenzene-reductant molar ratio of 1:100.

In **chapter 7**, CTAB complexed poly(3-thiophene ethanol)-functionalized multiwalled carbon nanotube nanocomposites (PTECNT-COOH) were prepared by a simple solution blending approach. The highly stable dispersion of nanocomposites in an ethanol medium has an advantage for solution processability. The PTECNT-COOH nanocomposites have good electrical conductivity and high thermal stability. Furthermore, electrochemical supercapacitor studies of nanocomposites were conducted for which modified glassy carbon electrodes could be prepared without adding additives or binders. The electrochemical performance of nanocomposites revealed the supercapacitor application of PTECNT-20 with a relatively good specific capacitance of 128 F/g. In addition, the composite exhibited excellent electrochemical stability by retaining 99 % capacitance even after 1000 cycles.

Way forward

Facile synthetic strategies would generate promising polythiophene carbon nanotube nanocomposites in various applications. The unique electrical, optical, thermal, and mechanical properties accomplished in such nanocomposites could result in finding suitable nanocomposite applications. We have reported some of these applications of nanocomposites. Furthermore, the prominent characteristic features of these reported nanocomposites may be extended to various other fields of application, including electromagnetic interference shielding, thermoelectric materials, sensor, photovoltaic applications and magnetism.

Publications and Conference Presentations

Journal papers

[1] T S Swathy, M Jinish Antony* and Naijil George. "Active Solvent Hydrogen Enhanced p-Nitrophenol Reduction Using Heterogeneous Silver Nanocatalysts@Surface Functionalized Multiwalled Carbon Nanotubes". *Industrial and engineering chemistry research*. Vol: 60, year: 2021, page: 7050-7054. *Publisher: ACS*. DOI: https://doi.org/10.1021/acs .iecr.1c01371

[2] T S Swathy, M Jinish Antony*. "Tangled silver nanoparticles embedded polythiophene functionalized multiwalled carbon nanotube nanocomposites with remarkable electrical and thermal properties". *Polymer*. Vol: 189, year: 2020, page: 122171. *Publisher: Elsevier*.
DOI: https://doi.org/10.1016/j.polymer.2020.122171

[3] T S Swathy, M Anne Jose, M Jinish Antony*, "AOT assisted preparation of ordered, conducting and dispersible coreshell nanostructured polythiophene MWCNT nanocomposites". *Polymer*. Vol: 103, year: 2016, page: 206-213. *Publisher: Elsevier*. DOI: http://dx.doi.org/10.1016/j. polymer.2016.09.047

[4] M Jinish Antony*, C Albin Jolly, K Rohini Das, T S Swathy "Normal and reverse AOT micelles assisted interfacial polymerization for polyaniline nanostructures". *Colloids and Surfaces A*. Vol: 578, Year: 2019, Page: 123627. *Publisher: Elsevier*
DOI: https://doi.org/10.1016/j.c olsurfa.2019.123627

Conference presentations

[1] T S Swathy, M Jinish Antony*, "Antibacterial Activity of Water Dispersible Polythiophene-Functionalized Multiwalled Carbon Nanotube-Silver Nanoparticles Ternary Nanocomposite". *International Conference on Energy and Environment-2019*, Dec 12-14, 2019, TKM College of Arts and Science, Kollam.

[2] T S Swathy, M Jinish Antony*, "In-situ synthesis and characterization of water dispersible and conducting polythiophene-functionalized multiwalled carbon nanotube nanocomposite". *International Conference on Supercapacitors, Energy Storage and Applications- 2019*, March 8-10, 2019, C-MET, Thrissur.

[3] T S Swathy, M Jinish Antony*, "Synthesis and characterization of highly conducting and dispersible nanocomposite of silver nanoparticles decorated on water dispersible polythiophene- multiwalled carbon nanotube nanocomposite" *International Conference on Chemistry and Physics of Materials 2018*, Dec 19-21, 2018. St. Thomas' College (autonomous) Thrissur.