



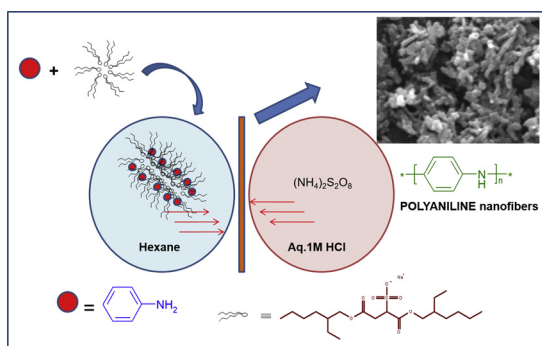
Normal and reverse AOT micelles assisted interfacial polymerization for polyaniline nanostructures



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GRAPHICAL ABSTRACT



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ABSTRACT

We report here the synthesis of polyaniline (PANI) nanomaterials using sodium bis (2-ethylhexyl) sulfosuccinate (AOT) micelles assisted chemical oxidative interfacial polymerization. We have employed two interfaces (chloroform-water and hexane-water) and two oxidizing agents (ammonium persulfate and ferric chloride). The anionic surfactant sodium bis (2-ethylhexyl) sulfosuccinate (AOT) forms normal micelles in aqueous solution and reverse micelles in hydrophobic solvents like hexane or chloroform. The factors influencing the properties and morphologies of polyaniline nanomaterials such as monomer: surfactant ratio, monomer: oxidant ratio, types of interfaces and oxidants used have been studied. Powder X-ray diffraction of the polyaniline nanomaterials have revealed that polyaniline samples were semi-crystalline in nature. Morphology of polyaniline samples studied by scanning electron microscopy (SEM) and transmission electron microscopy (TEM) have revealed that most of the polyaniline nanomaterials synthesized using ferric chloride possess spherical nature, whereas polyaniline samples synthesized using ammonium persulfate (APS) possess short nanofibers especially at lower aniline/AOT mole ratio in feed (12.5–6.5). The four probe electrical conductivity of the samples were found to be of the order of 1.8×10^{-1} to 8.6×10^{-1} S/cm. Thermal stability of the polyaniline samples recorded by thermogravimetric analysis (TGA) have revealed that polyaniline samples were thermally stable up to 275 °C for 10% weight loss. Interfacial polymerization of aniline monomer using reverse micelles of AOT in hexane phase and ammonium persulfate as oxidizing agent in aqueous phase have been proved to be efficient method for the synthesis of short polyaniline nanofibers.

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1. Introduction

Conducting polymers have been recognized as an important class of polymer materials as they find many applications in sensors, rechargeable batteries, corrosion protection, solar cells, antistatic coatings, and so on [1–10]. Conducting polymers have received wide attention mainly due to its characteristic features such as fast electrochemical responses, conducting or semiconducting behaviour, photo physical properties, mechanical stability, thermal/environmental stability, easy preparation and low cost of production [11–17]. The polyaniline nanomaterials have been synthesized mainly by physical or chemical methods. Physical methods such as electrospinning and electrochemical deposition are convenient for the production polyaniline nanostructures [18]. On the other hand, chemical methods utilize hard template or soft template or even template free methods for nanostructure formation [17,19–25]. Hard template method utilizes porous alumina or silica as hard template which should be removed after polymerization with special attention [19]. Soft template methods utilizes self-assembled soft materials such as surfactants or gels or colloidal systems or liquid crystals, as templates for the growth of micro/nanometer sized conducting polymers [16]. Soft templates are either easy to remove or they may become integral part of the conducting polymer with enhancement in properties such as conductivity and solubility [25–32]. Interfacial polymerization is another method which allows chemical oxidative polymerization of aniline monomer to take place at aqueous-organic interface [33–36]. Interfacial polymerization method has several advantages such as easy purification of products, reproducible results and good polymerization yield etc. Furthermore, interfacial polymerization can produce high quality polyaniline nanofibers with control over their size, morphology and nanofiber diameter [33]. The anionic surfactant sodium bis(2-ethylhexyl) sulfosuccinate (AOT) possess one polar head and two hydrophobic tail groups which has the unique ability to form normal micelles in water and reverse micelles in non-polar hydrophobic organic solvents [37–40]. Q Zhou et al reported the AOT assisted reverse micro emulsion polymerization of aniline for obtaining a relation between morphology and crystallinity by controlling the water content [Q Zhou et al reported the AOT assisted reverse micro emfs >].41]. F Zou et al reported AOT micellar solution assisted polymerization of aniline for the production of chiral polyaniline [42]. Although, micro-emulsion polymerization of aniline using AOT and other anionic surfactants have been reported, however, the role of various factors such as monomer : surfactant ratio, monomer : oxidants ratio, type of micelles and different interfaces utilized on the morphology, conductivity and solid state ordering have not explored in detail [43]. Two oxidizing agents (ammonium persulfate and ferric chloride) and two different interfaces (chloroform-water and hexane-water) have been utilized for the synthesis of polyaniline nanomaterials. In short, normal and reverse type micelles of AOT have been used as a soft template for the preparation of polyaniline nanostructures via interfacial polymerization using different interfaces and different oxidizing agents.

2. Experimental

2.1. Materials

Aniline, sodium bis(2-ethylhexyl) sulfosuccinate (AOT), ferric chloride and ammonium persulfate were purchased from Sigma Aldrich. Chloroform, hexane and acetone were purchased from Merck chemicals.

3. Measurements and instruments

The fourier transform infrared spectra of the samples were recorded by Shimadzu FT-IR spectrometer using KBr pellet method. UV-vis spectra of the samples were recorded by Shimadzu UV-vis spectrometer

in the range 200–700 nm in deionised water. Wide angle X-ray diffraction of the samples were measured using Anton Paar, TTK 450 with 2θ values ranging from 3 to 80 degrees. Scanning electron microscopy images of the samples were recorded by JOEL Model JSM - 6390 L.V. Transmission electron microscopic analysis was carried out by JOEL/JEM 2100 instrument having capacity of 200 KV and with magnification 2000X - 1,500,000 \times . Thermogravimetric analysis (TGA) of the samples was measured in Perkin Elmer, Diamond TG/DTA. The Four probe electrical conductivity of the samples were measured using

DFP-RM-200 four probe set up with constant current source Model CCS-01 and DC microvoltmeter.

4. General procedure

4.1. Preparation of polyaniline by normal AOT micelles assisted interfacial polymerization

4.1.1. Synthesis of PANI APS-1 N

Aniline (1 ml, 10.952 mmol) was added to chloroform (30 ml) in a 100 ml beaker. AOT (0.194 g, 0.438 mmol) was dissolved in hydrochloric acid solution (30 ml, 1 M) by sonication in a beaker. Ammonium persulfate (3.66 g, 16.428 mmol) was added to the AOT solution by sonication for 5 min. The surfactant + oxidant aqueous solution was added carefully along the side of the beaker to chloroform layer with minimum disturbance to the interface. After a short induction period of one minute, polyaniline formation takes place at the interface between the two immiscible layers. As the time progresses, more and more green coloured polyaniline is formed at the interface and finally settled down at the aqueous layer. The reaction mixture was kept undisturbed for 24 h. The reaction mixture was washed repeatedly with deionised water and acetone, until filtrate become colourless. The resulting polyaniline sample was dried in a vacuum oven for 12 h at 60 °C. Yield = 0.82 g (82%). FT-IR (KBr, cm^{-1}): 1564, 1495, 1296, 1135, 807 and 605.

A similar procedure was adopted to synthesize PANI APS-2 N using hexane-water interface instead of chloroform –water interface (see supporting information)

4.1.2. Synthesis of PANI Fe-1 N

Aniline (1 ml, 10.952 mmol) was added to chloroform (30 ml) in a 100 ml beaker. AOT (0.194 g, 0.438 mmol) was dissolved in hydrochloric acid (30 ml, 1 M) in another beaker by sonication. Ferric chloride (2.66 g, 16.428 mmol) was added to the AOT solution by sonication for 5 min. Rest of the procedure was similar to that of PANI APS-1 N. The resulting polyaniline sample was dried in a vacuum oven for 12 h at 60 °C. Yield = 0.076 g (7.60%). FT-IR (KBr, cm^{-1}): 1591, 1488, 1296, 1115 and 797.

A similar procedure was adopted to synthesize PANI Fe-2 N by using hexane-water interface instead of chloroform –water interface (see supporting information).

4.2. Preparation of polyaniline by AOT reverse micelles assisted interfacial polymerization

4.2.1. Synthesis of PANI APS-1R

Aniline monomer (1 ml, 10.952 mmol) was added to chloroform (30 ml) layer, which was pre-dissolved by AOT (0.194 g, 0.438 mmol) in a 100 ml beaker by sonication. Ammonium persulfate (3.66 g, 16.428 mmol) was dissolved in hydrochloric acid solution (30 ml, 1 M) in another beaker by sonication for 5 min. The ammonium persulfate solution was added carefully along the sides of the beaker containing aniline plus AOT mixture in chloroform layer with minimum disturbance to the interface. Rest of the procedure was similar to PANI APS-1 N. Yield = 0.89 g (89%) FT-IR (KBr, cm^{-1}) 1568, 1489, 1439, 1351, 1292, 1239, 1127.

A similar procedure was adopted to synthesize PANI APS-2R by using hexane-water interface instead of chloroform –water interface

(see supporting information).

4.2.2. Synthesis of PANI Fe-1R

Aniline monomer (1 ml, 10.952 mmol) was added to chloroform (30 ml) layer, which was pre-dissolved by AOT (0.194 g, 0.438 mmol) in a 100 ml beaker by sonication. Ferric chloride (2.66 g, 16.428 mmol) was dissolved in hydrochloric acid (1 M, 30 ml) by sonication in another beaker. Oxidizing agent solution was added slowly along the sides of the beaker containing aniline-AOT mixture with minimum disturbance to the interface. The Aniline-AOT mixture in chloroform forms lower organic layer and ferric chloride solution forms upper aqueous layer. Rests of the procedure were similar to that of PANI APS-1 N. Yield = 0.28 g (28%). FT-IR (KBr, cm^{-1}): 1564, 1485, 1300, 1244, 1131, 807 and 585.

A similar procedure was adopted to synthesize PANI Fe-2R by using hexane-water interface instead of chloroform-water interface (see supporting information).

5. Results and discussion

Polyaniline nanomaterials have been synthesized by normal and reverse AOT micelles assisted interfacial polymerization using two different interfaces such as chloroform-water and hexane-water interfaces and two different oxidizing agents such as ammonium persulfate and ferric chloride (see Fig. 1). The anionic surfactant AOT has the unique ability for the formation of normal micelles in aqueous solution and reverse micelles in non-polar hydrophobic organic solvents. In normal AOT micelles assisted interfacial polymerization, AOT plus oxidizing agents were present in aqueous phase and aniline in organic phase. In reverse AOT micelles assisted interfacial polymerization, AOT plus aniline monomer were present in organic phase and oxidizing agents in aqueous phase (see Fig. 1). In AOT normal micelles, polar head ($-\text{SO}_3^- \text{Na}^+$) of surfactant pointed out into the aqueous phase and non-polar double tail directed towards the inner phase of spherical micelles, whereas in reverse micelles, polar head ($-\text{SO}_3^- \text{Na}^+$) pointed out to the inner phase and non-polar double tail directed towards outer organic phase. We have carried out a detailed investigation on various factors such as different aqueous-organic interfaces, oxidizing agents and type of micelles (normal or reverse) that would have influenced the polyaniline nanomaterial formation. The two interfaces used were

chloroform-water and hexane-water represented as 1 and 2 respectively. Oxidizing agents were abbreviated as APS for ammonium persulfate and Fe for ferric chloride. The letter N was denoted for normal micelles and R for reverse micelles. PANI APS-1 N and PANI APS-1R means polyaniline synthesized by APS as oxidizing agent using chloroform-water interface in normal and reverse micelles respectively. Similarly, PANI Fe-1 N and PANI Fe-1R means polyaniline samples synthesized by ferric chloride using chloroform-water interface in normal and reverse micelles respectively.

We have kept the same monomer: surfactant ratio (1:1/25) and monomer: oxidant ratio (1:1.5) for the first series of polyaniline samples synthesized (see Table 1). In general for all polyaniline samples synthesized, oxidizing agents have been kept at aqueous phase and aniline monomer in organic phase, however, surfactant AOT was kept in aqueous phase for normal micelles and in organic phase for reverse micelles assisted interfacial polymerization. For the normal micelles assisted interfacial polymerization, aniline monomer was not stabilised by the surfactant (AOT), however, aniline monomer diffuse from organic phase to the interface containing AOT micelles plus oxidizing agents in aqueous phase. In reverse micelles assisted interfacial polymerization, aniline monomer was stabilised by AOT reverse micelles in hexane, which react with oxidizing agent present in the aqueous phase at the interface. AOT micelles stabilized aniline diffuse much more rapidly to the interface and produce polyaniline samples with good yield (see Table 1).

The polyaniline samples were subjected to FT-IR spectra for confirming the formation of polyaniline nanomaterials (see Fig. 2). Polyaniline samples synthesized using normal micelles (N) have shown characteristic peaks at 1568, 1492, 1298, 1242, 1137 and 808 cm^{-1} corresponding to quinoid stretch, benzenoid stretch, C-N stretch of secondary amine, NH polaron unit, C-H out of plane stretch and C-H deformation respectively. Polyaniline samples synthesized using reverse micelles (R) have shown characteristic peaks at 1571, 1489, 1292, 1236, 1129 and 815 cm^{-1} corresponding to quinoid stretch, benzenoid stretch, C-N stretch of secondary amine, NH polaron unit, C-H out of plane stretch and C-H deformation respectively [44,45]. The quinoid and benzenoid peaks at 1568 and 1492 cm^{-1} shows that polyaniline was in doped state. The stretching and bending modes were matching with the literature reports for polyaniline [44-47]. The elemental analysis results revealed that the polyaniline samples synthesized using

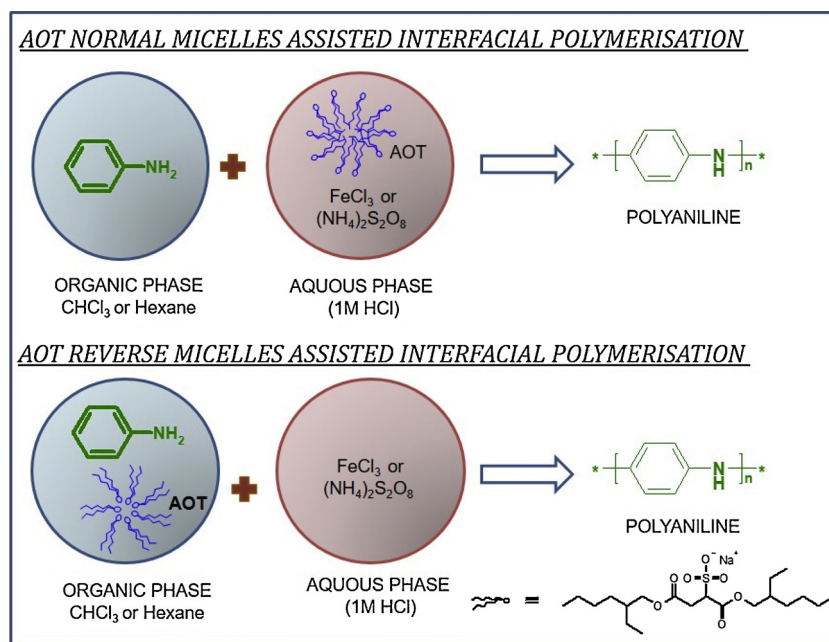


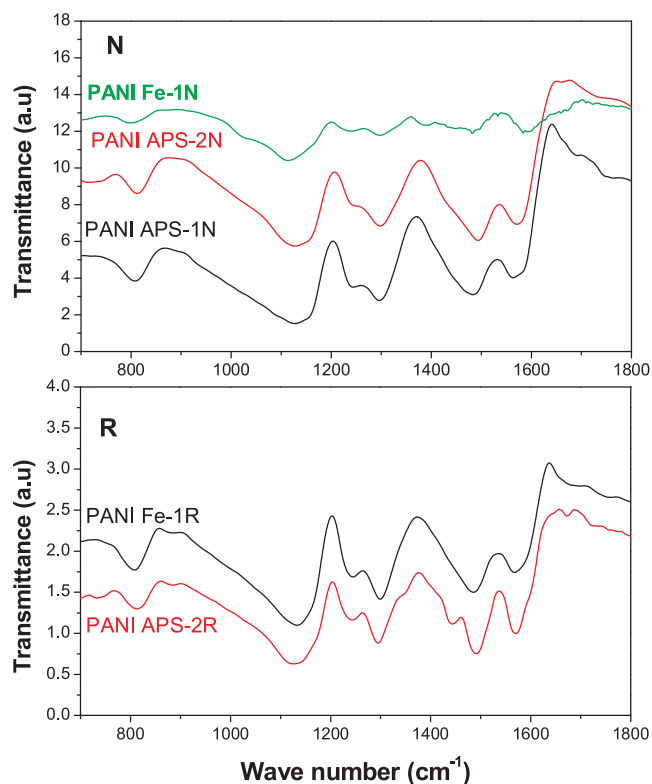
Fig. 1. Synthesis of polyaniline nanomaterials by normal and reverse AOT micelles assisted interfacial polymerization.

Table 1

Millimoles of aniline, millimoles of AOT, monomer: surfactant mole ratio, monomer: oxidant mole ratio, yield and conductivity.

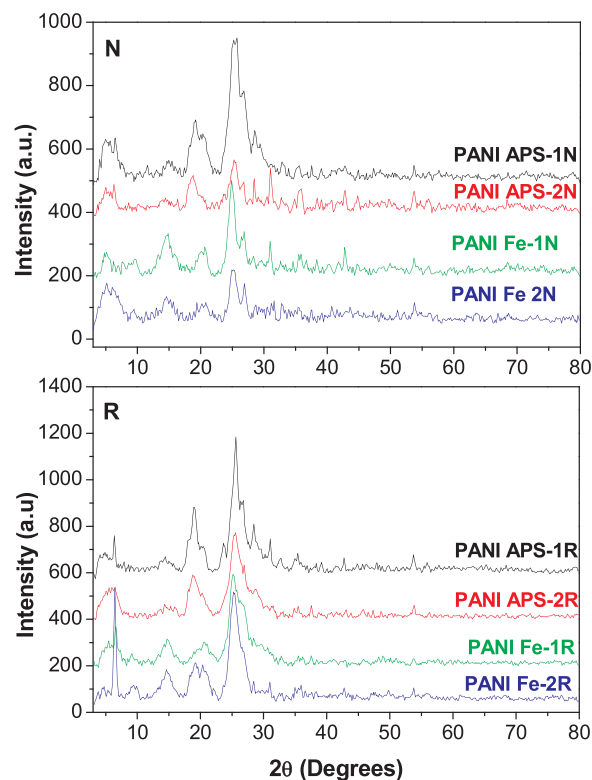
Samples	Aniline (mmol)	AOT (mmol)	Aniline: surfactant mole ratio	Oxidizing agent	aniline : oxidant mole ratio	Yield (%)	σ (S/cm)
PANI APS-1 N	10.952	0.438	1:0.04	APS	1: 1.5	82	0.345
PANI APS-2 N	10.952	0.438	1:0.04	APS	1: 1.5	53	0.230
PANI APS-1R	10.952	0.438	1:0.04	APS	1: 1.5	89	0.217
PANI APS-2R	10.952	0.438	1:0.04	APS	1: 1.5	83	0.184
PANI Fe-1 N	10.952	0.438	1:0.04	Fe	1: 1.5	7.6	*
PANI Fe-2 N	10.952	0.438	1:0.04	Fe	1: 1.5	10	*
PANI Fe-1R	10.952	0.438	1:0.04	Fe	1: 1.5	28	0.404
PANI Fe-2R	10.952	0.438	1:0.04	Fe	1: 1.5	28	0.546

*Conductivity did not checked due to poor yield.

**Fig. 2.** FT-IR spectra of polyaniline samples a) PANI Fe-1 N, PANI APS-2 N and PANI APS-1 N b) PANI Fe-1R and PANI APS-2R.

ammonium persulfate contain more sulphur content (2.98–5.08 %) and higher S/N ratio (0.31–0.49) than polyaniline samples synthesized using ferric chloride (see in supporting information Table 1). During polymerization process ammonium persulfate and ferric chloride furnish sulfate anion and chloride anion respectively, which will be available as dopant anion in addition to acid (HCl) doping. The presence of dopant anions such as sulfate anion (from oxidizing agent) and sulfonate anion (from AOT) could improve the sulphur content of polyaniline samples depending on the oxidising agent taken. Although polyaniline samples synthesized using ferric chloride have low sulphur content (0.15–0.29%) arising from sulfonate anion of AOT, however doping would be completed in presence of hydrochloric acid. Stronger oxidizing agent such as ammonium persulfate with higher standard electrode potential (+ 2.01 V) produce more yield of polyaniline samples in interfacial polymerization than weaker ferric chloride oxidising agent with lower standard electrode potential (+ 0.77 V).

Solid state ordering of the polyaniline samples were studied by powder wide angle x-ray diffraction (see Fig. 3). The x-ray diffraction pattern of the polyaniline samples synthesized by both normal and reverse AOT micelles were shown sharp semi-crystalline peaks at 2θ

**Fig. 3.** WXR D pattern of the polyaniline synthesized by normal micelles (top) and reverse micelles (bottom) assisted interfacial polymerization.

values 5.6, 19.6, and 25.5 degrees [44–49]. Polyaniline samples synthesized by soft templates such as emulsion, gel or dopant assisted polymerization usually results in amorphous or partially crystalline materials. The semi-crystalline peaks in the present case mainly due to the interface directed controlled growth of polyaniline chain.

The polyaniline samples were easily dispersible in deionised water by sonication, which enabled us to record the UV absorption spectra of these nanomaterials in solution (see Fig. 4). Polyaniline samples synthesized using APS as oxidizing agent such as PANI APS-1 N, PANI APS-2 N, PANI APS-1R, PANI APS-2R were shown π - π^* transition at 232 nm, benzenoid peak at 290 nm, π -polaron broad peak in the range 350–450 nm and bipolaron peak tailing over 700 nm [44–51]. The polyaniline samples synthesized using ferric chloride as oxidizing agent such as PANI Fe-1 N, PANI Fe-2 N, PANI Fe-1R and PANI Fe-2R were shown a broad π - π^* transition at 232 nm which was extended as shoulder upto 320 nm, whereas polaron and bipolaron absorption bands were very weak. The electrical conductivity of the samples were measured by four probe electrical conductivity meter at four different points and average value was reported (see Table 1). The electrical conductivity of all the polyaniline samples were within the range 0.18

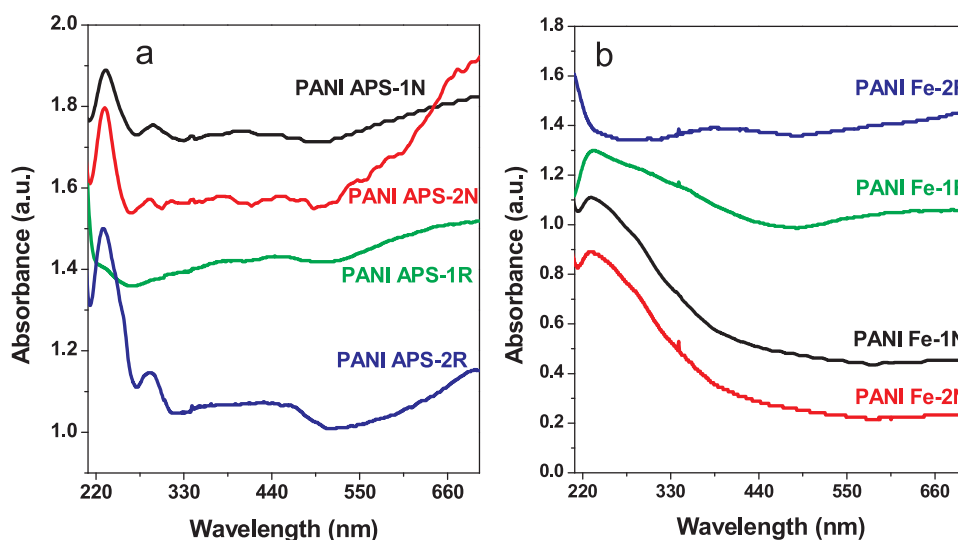


Fig. 4. UV-vis absorption spectra of the polyaniline samples synthesized using a) ammonium persulfate as oxidizing agent and b) ferric chloride as oxidizing agent.

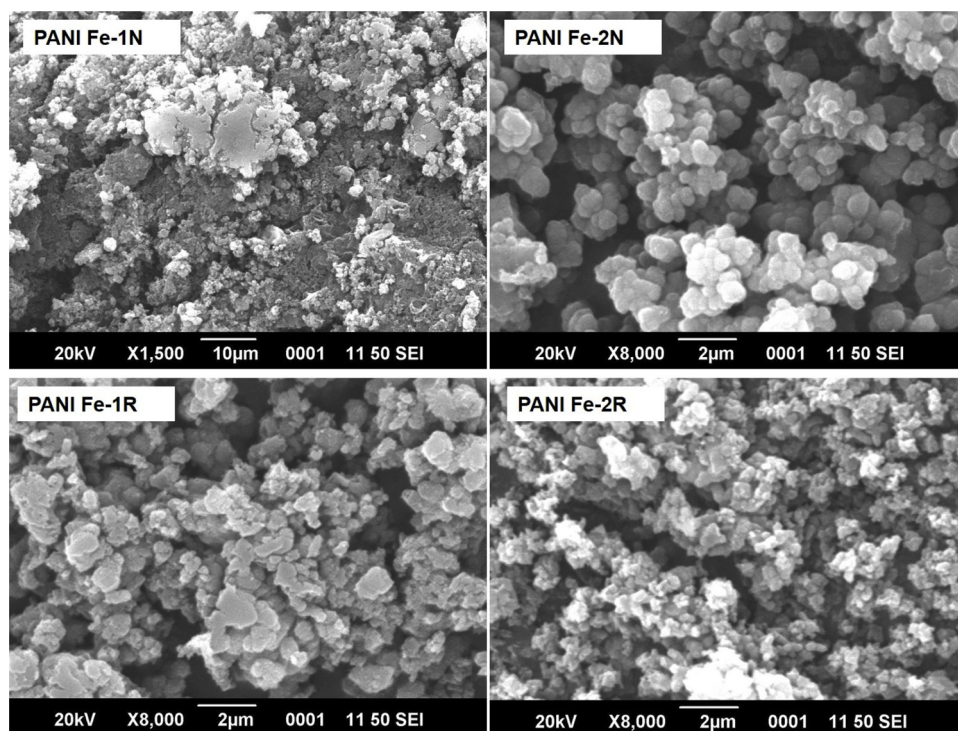


Fig. 5. SEM images of PANI Fe-1 N and PANI Fe-2 N, PANI Fe-1R and PANI Fe-2R.

to 0.58 S/cm, except for PANI-Fe 1 N and PANI-Fe 2 N which have very poor yield to measure the electrical conductivity [44–50]. The surface morphology of all polyaniline samples were taken by scanning electron microscopy (SEM). Polyaniline samples synthesized using ferric chloride as oxidizing agents like PANI Fe-1 N, PANI Fe- 2 N, PANI Fe-1R and PANI Fe-2R have spherical shape with average size 600 ± 30 nm (average diameter taken from 20 spheres). Both normal and reverse AOT micelles assisted interfacial polymerization using ferric chloride produces the spherical morphology (see Fig. 5). Polyaniline samples like PANI APS-1 N, PANI APS-2 N, PANI APS-1R and PANI APS-2R synthesized using ammonium persulfate have irregular shape (see Fig. 6). It was interesting to see that sample PANI-APS-2R prepared by hexane–water interface and APS as oxidizing agent have short nanofiber morphology in most of the area (shown by red colour in Fig. 6). The nanofiber forming tendency of PANI-APS-2R prompted us

to vary its aniline: AOT mole ratio and aniline: APS mole ratio in feed to understand the morphology of polyaniline. The aniline/ AOT mole ratio was changed from 25 to 6.25 (higher to lower aniline amount) and also monomer: oxidant ratio used was varied as 1: 1.5, 1: 1 and 1: 0.5 (see Table 2).

The sample PANI APS-2R sample have been further renamed as PANI APS-2R1 for convenience. The polyaniline samples were further synthesized by changing the monomer: surfactant ratio and monomer: oxidant ratio in feed for PANI APS-2R1 represented as PANI APS-2R2, PANI APS-2R3, PANI APS-2R4, PANI APS-2R5 and PANI APS-2R6 (See Table 2 and also supporting information for synthesis). The interfacial area for polymerization have kept constant (in 100 ml beaker, interfacial surface area equal to 78.5 cm^2), but the concentration of aniline was systematically reduced in feed for optimizing the nanofiber formation of polyaniline. By lowering the aniline amount in a fixed

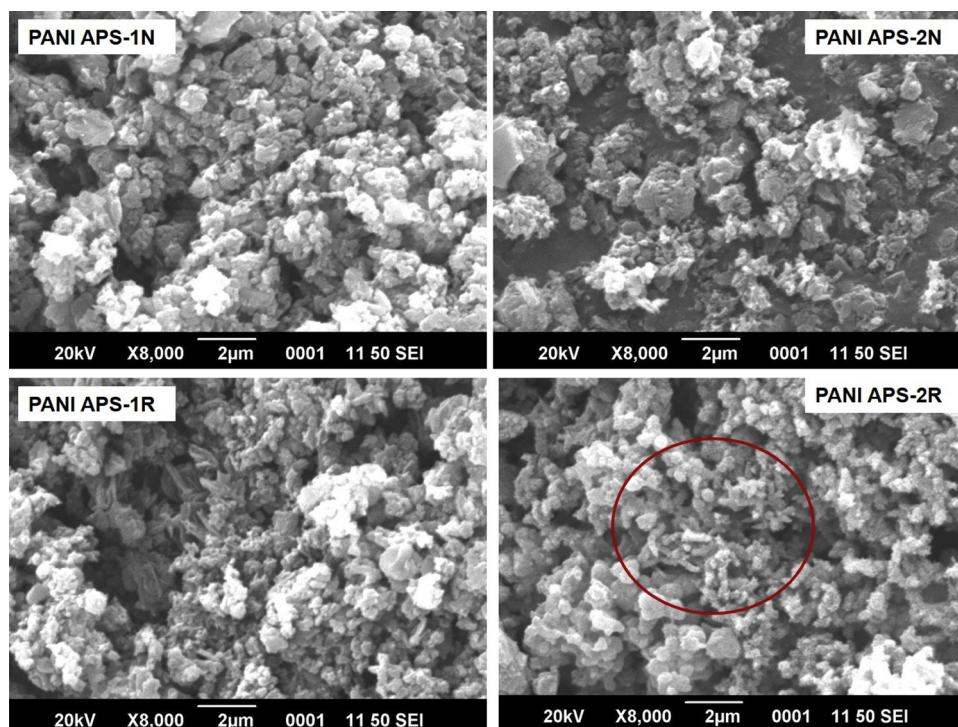


Fig. 6. SEM images of PANI APS-1 N, PANI APS-2 N, PANI APS-1R and PANI APS-2R.

Table 2

Millimoles of aniline, millimoles of AOT, monomer: surfactant ratio, monomer: oxidant ratio, yield and conductivity.

Samples	Aniline (mmol)	AOT (mmol)	Aniline : surfactant mole ratio	Morphology	Aniline: oxidant ratio	Yield (%)	σ (S/cm)
PANIAPS-2R1	10.952	0.438	1: 0.04	Nanofibers + spheres	1: 1.5	83	0.184
PANIAPS-2R2	5.476	0.438	1: 0.08	Nanofibers	1: 1.5	33	0.584
PANIAPS-2R3	5.476	0.438	1: 0.08	Nanofibers	1: 1	37	0.860
PANIAPS-2R4	2.738	0.438	1: 0.16	Nanofibers	1: 1	15	*
PANIAPS-2R5	5.476	0.438	1: 0.08	Nanofibers	1: 0.5	24	*
PANIAPS-2R6	2.738	0.438	1: 0.16	Nanofibers	1: 0.5	13	*

*Conductivity did not checked due to poor yield.

surfactant concentration, surfactant content in aniline: surfactant ratio goes up as shown in Table 2. Therefore the electrical conductivity of the polyaniline samples also increases from 0.184–0.860 S/cm as result of doping. The scanning electron microscopy images of the newly synthesized polyaniline samples were shown in Fig. 7. The morphology of the polyaniline samples were changed from the non-uniform morphology to short nanofibers with diameter 80 ± 30 nm. The reverse micelles of AOT (R) can stabilize the aniline monomer particularly at low aniline/ AOT mole ratio (12.5 to 6.25) which could be driving force for the nanofiber formation. The transmission electron microscopic analysis of the PANI APS-2R2, PANI APS-2R4 and PANI APS-2R5 have shown that the solid nanofibers with size in the range 50 ± 10 nm (see Fig. 8). The electron diffraction pattern of PANI APS-2R5 have shown bright spot corresponding to crystalline domains (see Fig. 8). The semi-crystalline nature of the polyaniline samples obtained from the selected area electron diffraction studies was in accordance with x-ray diffraction studies.

The mechanism of formation of the polyaniline nanofibers in AOT reverse micelles assisted interfacial polymerization was schematically shown in Fig. 9. The spherical reverse micelles of AOT surfactant in hexane undergo aggregation with aniline to form cylindrically aggregated micelles [38,39]. The cylindrically aggregated micelles of AOT move towards the interface and get polymerized by ammonium persulfate present in aqueous phase to produce polyaniline nanofibers. In normal micelle phase assisted polymerization, aniline monomer present

in organic phase diffuse towards the interface and get polymerized by the oxidizing agent present in spherical micelles of AOT. Thermogravimetric analysis of the polyaniline samples synthesized by chemical oxidative interfacial polymerization have shown good thermal stability of 280 °C for 10% weight loss irrespective of the oxidizing agents used shown in Fig. 10 [44,47].

6. Conclusion

Polyaniline nanomaterials have been synthesized via sodium bis(2-ethylhexyl) sulfosuccinate (AOT) micelles assisted interfacial polymerization using two different oxidizing agents and two different interfaces. AOT normal micelles in aqueous phase and reverse micelles in organic phase have been utilized for interfacial polymerization of aniline. Important outcomes of the present studies are summarized as follows i) Polyaniline nanomaterials have shown characteristic infrared absorption bands of polyaniline nanomaterials ii) The UV–vis absorption spectra of the polyaniline nanomaterials have shown three distinct peaks, sharp peak at 232 nm, broad peak within the range 350–450 nm region and broad peak tailing over 700 nm corresponding to π - π^* , π -polaron and bipolaron transitions respectively iii) The oxidizing agent ferric chloride produce less polymeric yield in comparison to ammonium persulfate iv) Scanning electron microscopy analysis revealed that the polyaniline samples prepared using ferric chloride have spherical shape with size $600 \text{ nm} \pm 50 \text{ nm}$, whereas, polyaniline samples

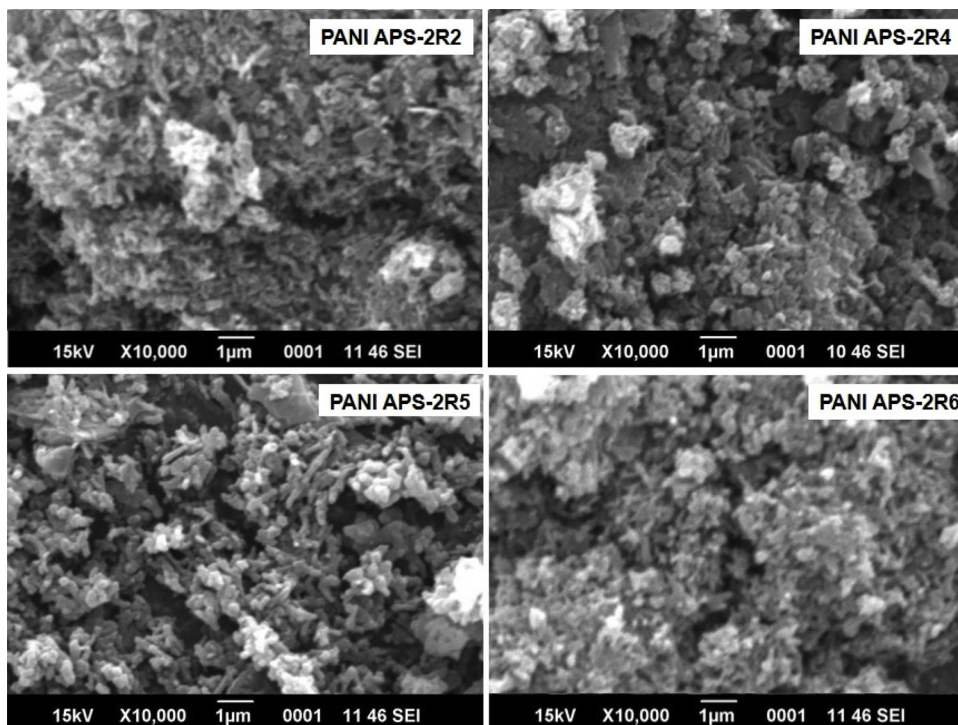


Fig. 7. SEM images of PANI APS-2R2, PANI APS-2R4, PANI APS-2R5 and PANI APS-2R6.

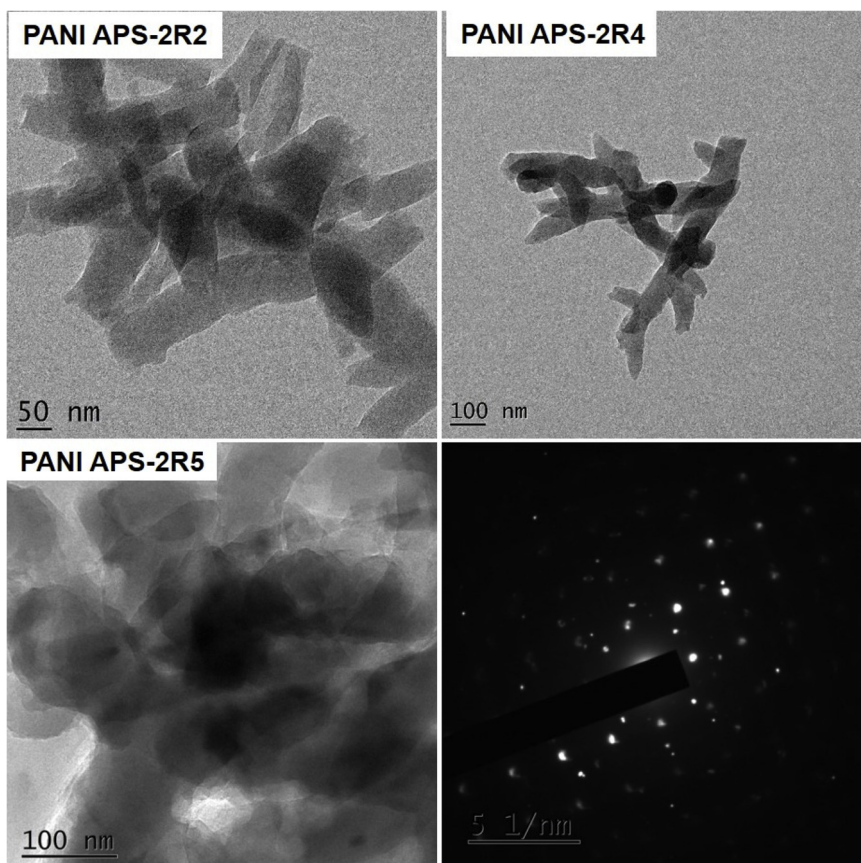


Fig. 8. TEM images of PANI APS-2R2, PANI APS-2R4 and PANI APS-2R5 and selected area electron diffraction images PANI APS-2R5.

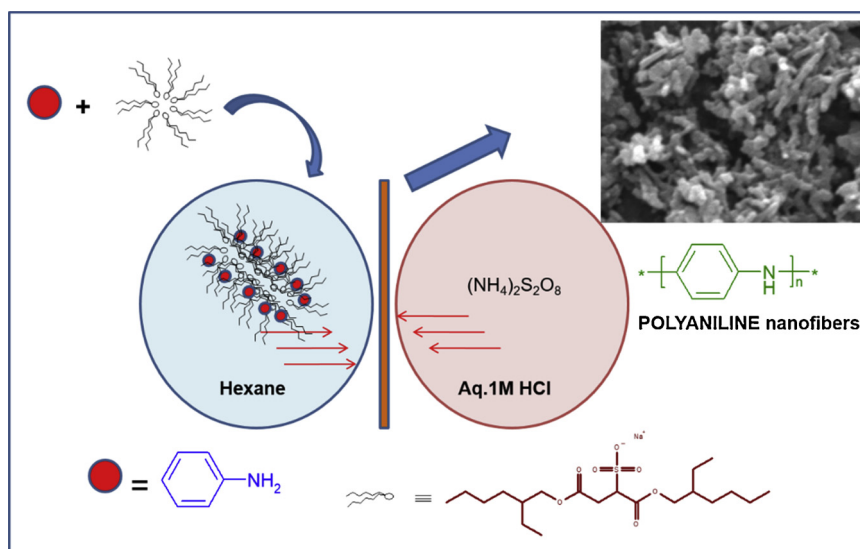


Fig. 9. Schematic representation of mechanism of nanofiber formation in reverse AOT micelles assisted interfacial polymerization.

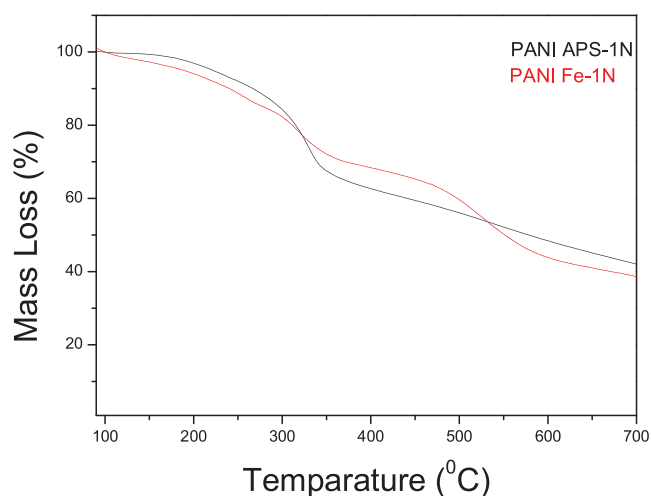


Fig. 10. Thermogravimetric analysis (TGA) of the polyaniline nanomaterials.

synthesized using APS possess short nano fibers with diameter 70 ± 30 nm v) Interfacial polymerization of aniline prepared in hexane-water interface and ammonium persulfate as oxidizing agent have produced exclusive formation of polyaniline nanofibers at low aniline amount in feed (aniline/AOT mole ratios, 12.5–6.5) vi) Mechanism proposed suggest that AOT reverse micelles initially formed were aggregated with aniline to form aniline + AOT cylindrically micelles in organic phase, which upon interfacial oxidative polymerization results in polyaniline nanofibers vii) TEM images of polyaniline samples clearly shown the formation of solid nanofibers in the case of PANI APS-2R2, PANI APS-2R4 and PANI APS-2R5 viii) Sharp semi-crystalline peaks in powder x-ray diffraction of polyaniline sample indicates the controlled and directional growth of polymer chain at the interface, which further evidenced by the bright spots in electron diffraction pattern ix) Polyaniline samples synthesized by both ammonium persulfate and ferric chloride were thermally stable up to 270 °C for 10% weight loss. x) Among the two organic phase (hexane and chloroform), highly non-polar and six carbon hexane solvent have been effective solvent for formation of reverse micelles of AOT and hence for the production of short polyaniline nanofibers.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.colsurfa.2019.123627>.

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