

## Some aspects of chemical procedures & application trends of polyaniline as an intrinsically conductive polymer

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**Abstract:** Intrinsically conducting polymers (ICPs) have been studied extensively due to their intriguing electronic and redox properties and numerous potential applications. Polyaniline, its derivatives and composites has been recognized as ICPs. These polymers are attractive materials owing to good stabilities, easy synthesis, desirable conductivity; exhibits extraordinary electronic properties. Because of this; they finds a wide variety of applications such as electromagnetic, interference shielding, energy storage, catalysis, chemical sensing, biochemistry, smart clothing, corrosion devices and microwave absorption industries. However, it is inherently brittle and poor in processability; To improve these restrictions and extend it functions, the fabrication of it advanced composites has attracted a great deal of attention & various procedures have been adapted. The scaled-up assays in this area, offers a wide scope of scattered literatures frequently utilized for “experts in the field”. Assembling this ill-matched data was the main purpose our ventures in this article. Science; Assays, gaps, particular themes in other papers overall assessed; aligned in this review article & outlined in sub-topics such as fundamental concepts, engaging procedures, improvement methods and application trends for emerge literature approvable in advanced science & educational journals.

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### 1. Introduction

#### 1.1. Some fundamental concepts & research importance angle

With the discovery in 1970 of intrinsically conductive polymers (ICPs), an attractive subject of research was initiated because of the interesting properties and numerous application possibilities of ICPs and since the successful synthesis of conducting polyacetylene in 1977 by Shirakawa et al, ICPs have generated tremendous interest due to their potential applications in various fields such as electromagnetic interference shielding, energy storage, catalysis, chemical sensing, biochemistry, smart clothing, corrosion devices electrochromic display devices, separation membranes, anticorrosive coatings and microwave absorption industries.

ICPs are inherently conducting in nature due to the presence of a “*conjugated electron system*” in their structure. ICPs have a low energy optical transition, low ionization potential and a high electron affinity. A high level of conductivity (near metallic) can be achieved in ICPs through oxidation–reduction as well as “*doping*” with a suitable dopant. ICPs are a novel class of “*synthetic metals*” that combine the chemical, electrochemical and mechanical properties of polymers with the electronic properties of metals and semiconductors. Although a variety of ICPs have been

synthesized and investigated, polyaniline (PANI) is known as having, probably the best combination of environmental stability, good conductivity and low cost. The field of PANI’s composites will be widely discussed & expand because from economic point of view, PANI is significantly superior to other ICPs, the aniline monomer is less expensive than the other monomers used for ICP. The synthesis of PANI is very simple, properties can be tuned easily, and it has numerous application possibilities . As a consequence, polyaniline , its derivatives and composites have very strong potential on a large scale for the industrial applications mentioned above and many of the other potential uses for it have yet to be explored because of a number of obstacles that need to be overcome. All these factors contribute to PANI being superior to other ICPs.

On the other hand, PANI is hygroscopic, mechanically weak and its processability is poor, it degrades before melting, it is insoluble in common organic solvents, it is soluble only in concentrated sulfuric acid under specific conditions. The common usage of this material has been restricted due to its insolubility, infusibility, modest environmental stability, and incompatibility with common polymers due to the rigid chain originating from an extended conjugated double bond which renders it unprocessable. However, limitations of processability such as low mechanical

strength, poor flexibility have prevented PANI from making significant commercial impact. Special attention is paid to improve the processability of the PANI and several approaches have been developed, various procedures and improvement methods and processes, have been adapted. The scaled-up and reliable procedures for optimize electrical conducting & enhance processability offers a wide range of possibilities to preparation it composite materials for extend it functions & expand further applications. A wide range of procedures, composites, strategies for change reaction mediums for improvement of PANI's composite restrictions that in various literatures were scattered; outlined by disciplines of educational literatures in this article [1,2].

### 1.2. Aim of this review

Since a vague signpost or a detour down a side trail could well have audience of journal lost and wondering, for help them that follow the development of article's contents, was attempted clear signals in the form of clearly worded topic sentences, relevant support, reasonable interpretations of material, and logical conclusions authorized. In the other researches & review literatures, there are common literature procedure of hard approach, introducing of total or few application aspects & regretfully follow a lot of obscure sources have been demonstrated, therefore in practice, mostly utilized for "experts in the field". Furthermore web texts of other review articles about application aspects of ICPs & PANI, accompanied in the way majority of nonscientific aims.

In this work, catching the attention of a wide audience will be purposed; therefore in the first place, only useful references, i.e. mainly primary, facile available, reliable & essential sources have been referenced, interpreted the literature rather than just listing results and if two or more authors disagree, express who is correct, were avoided topics that require hard-to-get documents such as patents, government reports or obscure journals; Second, chief points of recent articles edited in a flexible & expandable literature with supported of trace engaging aspects of PANI such as its advanced composites, fundamental concepts based on recent approaches, terms of polymerization conditions, some of it applications and so on. In the third place, an enjoyable article was authored that research motivation aspects is overcome & supported by persuasive evidence, therefore any current interested to polymeric chemists in all levels can utilized it.

In the field of ICPs based on PANI, chief points including chemical, electrochemical, template, enzymatic, plasma, photo and a number of other procedures. Which of this items is again subdivided; such as, chemical polymerization is subdivided into

heterophase solution, interfacial, seeding, metathesis, self-assembling, sonochemical etc. polymerizations. The rapidly expanding subjects of these procedures are generating many exciting new materials with novel properties. It is therefore, of immense significance to explore whether & applying of conducting polymers can lead to better performance in these already established areas, and whether reliable and scalable synthetic methods can be developed for the procedures of produce conducting polymer composites in order to provide the necessary materials base for both research and applications. The main objective of the present article is the matching of chief points from various literatures such as: polymeric conductivity & processibility fundamentals, setups, procedures and to penetrate into exact application aspect of them. The aim of this attempt was to produce/show derivatives, grafts, blends & composites of PANI companion in the way, provide specific application.

Since the various procedures, chemical improvements & processes, application aspects scaled-up, enormously expanded & overlapped in the available literature reviewed for this study; as mentioned above, attempts only *"useful & engaged of them, instanced to make this article to form clear ideas of investigate subject and for enhance visualization of interests in the field"*. In other word, these articles creates reader's interest in the subject of ICPs based on PANI composites and provide them with enough & exact information about field's topics to understand other expert research sources that have enough & exact experimental methods, results and discussion.

### 2. General baseline

The ICPs polymers are conducting systems that have conjugated  $\pi$  electrons. Conjugated polymers consist of alternating single and double bonds, creating an extended network. The movement of electrons within this framework is the source of conductivity. However, dopant is required to increase the level of conductivity for this type of polymers. The ability of polymers to become electrically conductive was shown when a scientific breakthrough demonstrated that to become electrically conductive, a polymer must imitate a metal, which means that electrons in polymers must be free to move and must not be bound to atoms. Most polymeric materials are poor conductors of electricity because a large number of free electrons are not available to participate in the conduction process. In principle, an oxidation or reduction reaction is often accompanied by the addition or removal of electrons. Therefore, a polymer might become electrically conductive by removing electrons, a process described as *"doping"*.

Amongst the generation of ICPs, polyaniline (PANI) is one of the most promising candidates and a lot of

studies have been devoted to the polymer. The reason is that PANI is easy to synthesize and is rather environmental stable combined with a high conductivity (Figure 1). However, PANI in its conducting form is also intractable in nature. Subsequent developments to modify PANI into a processable form by means of counter ion induced processing, backbone substitution with alkyl chains etc. led to the use of PANI in a number of applications, usually in (nano)composites where PANI in dispersed form acts as a conductive filler. Upon mixing PANI with conventional polymers, the strong

electrostatic interactions between PANI molecules results in a phase segregated morphology leading to loss of connectivity between the dispersed PANI particles and hence poor conductivity. Thus, a high(er) filler content is a prerequisite to achieve the necessary so-called “*percolation threshold*”. The downside of increasing the PANI concentration is a loss in physical and mechanical properties of the composite/blend(Figure1)[3].

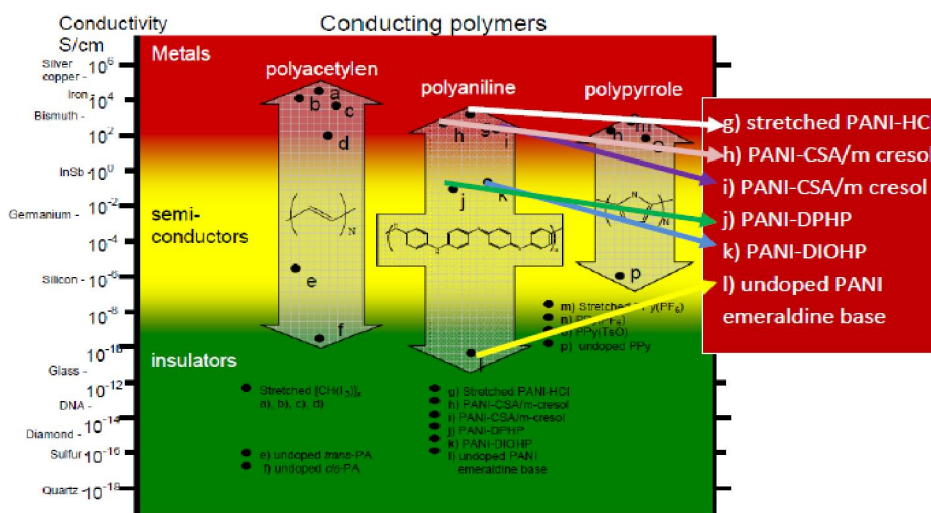


Figure 1. Electrical conductivity of PANI as a ICPs (original Figure from[3])

## 2.1. The course of aniline oxidation at various acidities

Polyaniline is typically prepared by the chemical oxidation of aniline or anilinium salts, such as aniline hydrochloride or aniline sulfate, in acidic aqueous medium, ammonium peroxydisulfate (APS) being the most common oxidant (Figure 2). Hydrogen atoms abstracted from the aniline molecules during their coupling to oligomeric and polymeric structures are released as protons, i.e., sulfuric acid is a by-product. The pH thus always decreases in the course of aniline oxidation. Such process is sometimes called a “*falling pH*” method of PANI preparation [4,5].

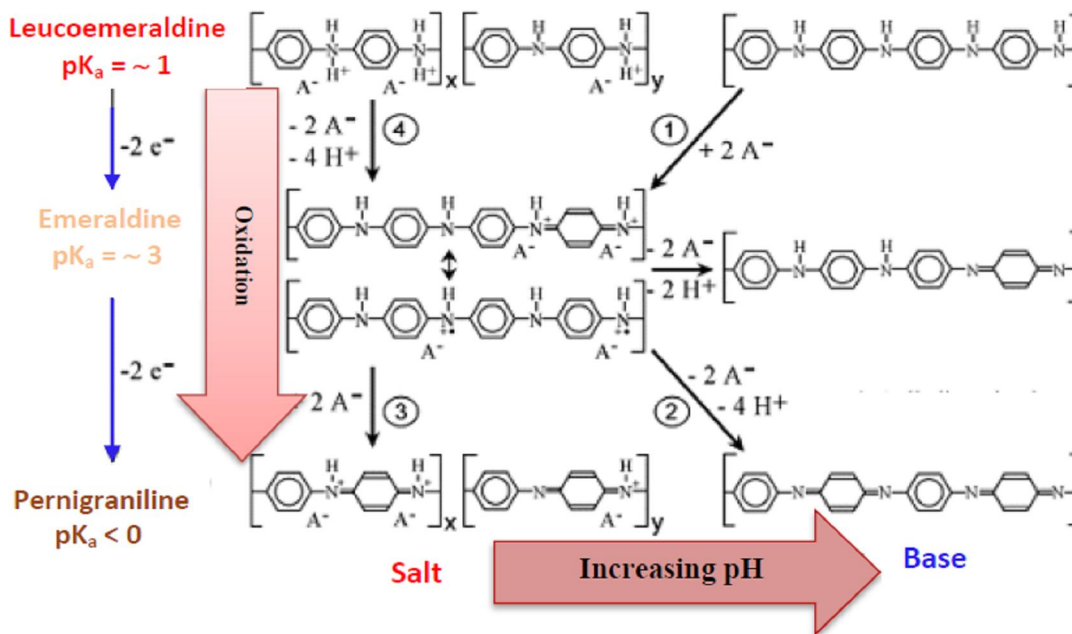
PANI is a semi-crystalline, heterogeneous system with a crystalline (ordered) region dispersed in an amorphous (disordered) region as shown in Figure 3d. It is similar to a Quasi-Metallic Island surrounded by a non-metallic amorphous zone (Figure 3). The crystalline domains are metallic in nature, where conduction occurs through electron delocalization or hopping of the charge carrier due to the ordered structure. The conduction in the metallic region occurs

by the hopping of charge carriers through the polaron structure [5].

## 1. Some approaches for the synthesis of PANI

### 2.1 Interfacial polymerization

Water-soluble polyaniline can be prepared via the interfacial polymerization route in the presence of PSS dispersed in the water phase. In this setup, the aniline monomers and the PSS are dissolved in  $\text{CHCl}_3$  organic phase and the aqueous phases, respectively, with the reaction taking place at the interface. Polyaniline is formed at the interface where the aniline monomer and PSS are found within 10 min in a process by which aniline is protonated by the PSS in the presence of the oxidant, ammonium persulfate. During this oxidative polymerization of aniline, the PSS act as a proton source for the doping agent and provides the necessary counterions to the developing charged polyaniline. The excess sulfonic groups can improve water-soluble properties and the resultant polyaniline easily dispersed in aqueous solution(Figure 4.) [6].



**Figure 2.** Polyaniline (PANI) has three electrochemical states: leucoemeraldine, emeraldine, and pernigraniline. Not only are ions exchanged, but in aqueous electrolytes there is also proton exchange, since the different states have difference  $pK_a$ . In PANI is thus considerably more complex to use for actuators, since oxidation can result in either an expansion or a contraction, depending on pH [6].

### 2.2 Rapid mixing of reactants

This is the simplest method for synthesizing PANI and in place of conventionally slow addition of the aqueous APS solution, the aniline monomer is mixed rapidly with APS solution. Here, the initiator molecules are consumed rapidly after the initialization of the polymerization reaction due to the even distribution of aniline monomer and APS molecules in the solution [7].

### 2.3 Sonochemical synthesis

Jing et al.(2007) has reported the synthesis of PANI similar to the synthesis procedure of conventional PANI. The acidic APS solution is

added dropwise to an acidic aniline solution, and subjected to the ultrasonic irradiation which results to the high yield of PANI. It has been found that the excessive addition of aniline monomer or APS could contribute to the continuous formation of the primary PANI products or could lead the agglomeration of PANI. Unlike conventional procedure where irregular morphology of PANI is obtained, the sonochemical synthesis strictly prevents the further growth and agglomeration and thus, generates uniform morphology of PANI [8]. Figure 5 shows SEM images of dried-down polyaniline colloids [8].

Physical terms	Chemical terms	
Non-doped state		Undistributed conjugation
Neutral soliton		Free radical
Positive soliton		Carbocation
Negative soliton		Carbanion
Positive polaron		Radical cation
Negative polaron		Radical anion
Positive bipolaron		Carbocation
Negative bipolaron		Carbodianion



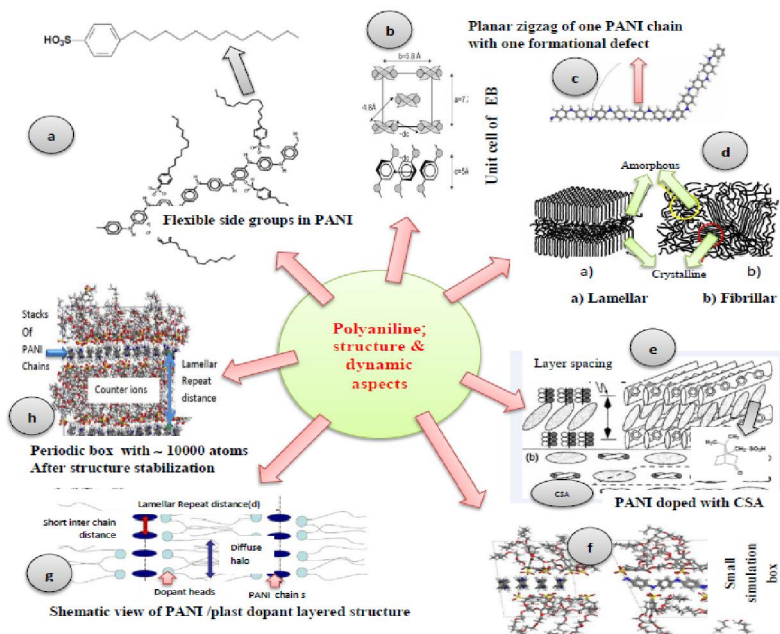
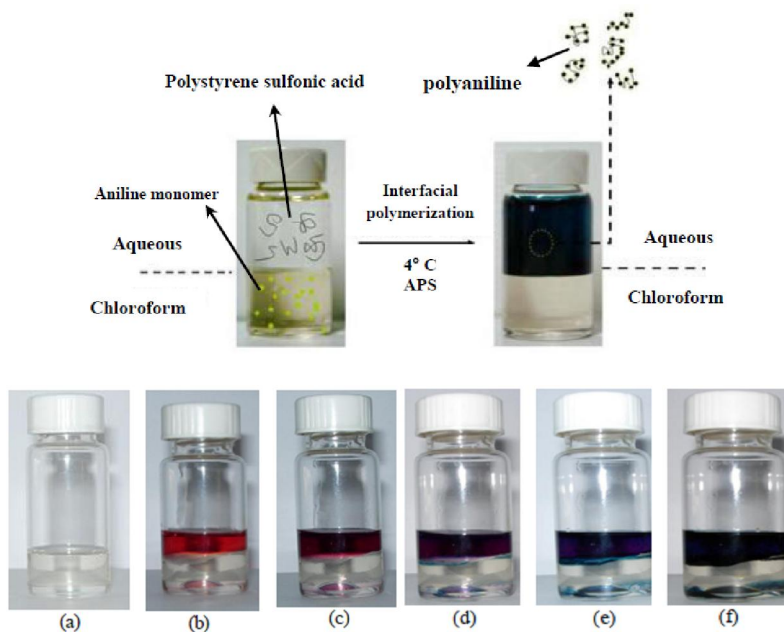


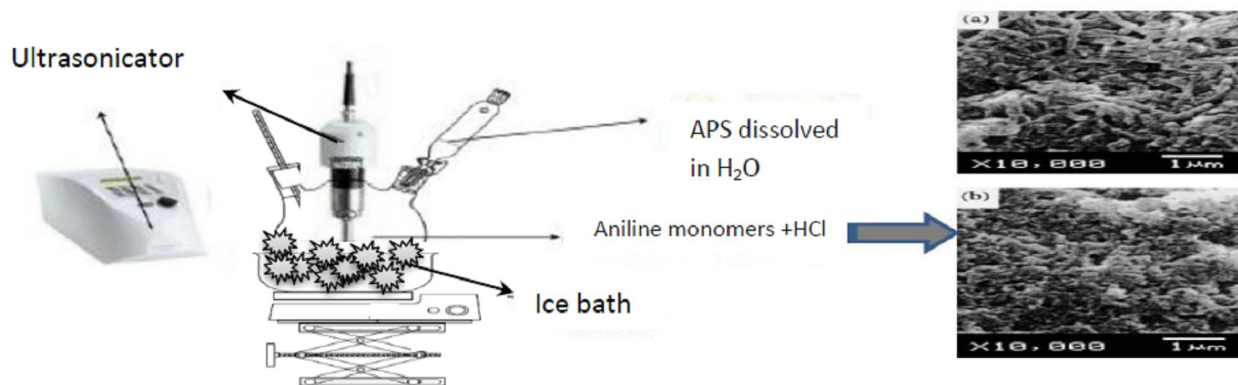
Figure 3. some aspects of structure & dynamic of PANI (original Figures from [5] ).



**2.4. Electrophoretic synthesis**

The first step of a reaction requires a preparation of conducting PANI through the chemical procedure using APS as oxidant. In the second step, a stock solution of

PANI (1 mg/ml) is prepared in the formic acid and the colloidal suspension is prepared by adding 100 ml of the stock solution into acetonitrile for the preparation of an electrolyte. In the colloidal suspension,



**Figure 5 .** Polymerization of aniline under ultrasonic irradiation . SEM photographs of the dried-down polyaniline colloids formed (a) without and (b) with ultrasonication (SEM Figures from [8] ) .

PANI dissociate into ions due to high dielectric medium which is offered by acetonitrile and thus, results to the formation of the positively charged PANI. The last step involves the electrophoretic film deposition where under the influence of applied voltage for a required time duration, positively charged colloid spheres of PANI in acidic colloidal suspension starts moving towards the negatively biased fluorinated tin oxide glass (FTO) electrode. This stepwise growth synthesis produces the uniform nanostructures of PANI on the surfaces of the FTO glass substrates [8].

## 2.5. Kinds of Doping

### 2.5.1. Self-doping

'Self-doping' is the most successful approach for increasing the solubility of conductive polymers in aqueous solution. When ionizable functional groups that form negatively charged sites are attached to the polymer chain to make the polymer conducting, it is referred to as 'self-doping' or when the group is an acid, 'self-acid-doping'. The distinctive properties of self-doped conducting polymers are their water solubility, electroactivity and conductivity over a wider pH range (in the case of polyaniline), and thermal stability [9].

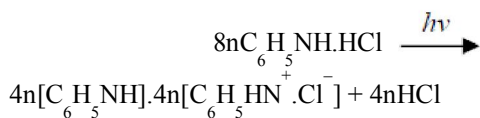
### 2.5.2. Secondary doping

It was shown that the effect of the secondary doping was based primarily on a change in molecular conformation of the polyaniline from compact coil to expanded coil. The secondary dopant is an inert substance solvent. Its function is to solvate the counter anions of the polymers; increase the repulsion between positively charged polymer backbones; decrease the aggregation and, therefore, increase the crystallinity and conductivity of the polymer films. The interaction between solvent molecules and polyalkylthiophene had been reported in the literature. The degree of conjugation in doped regio-regular polyalkylthiophene

solutions related directly to the dielectric constants of the solvents [9].

### 2.5.3. Radiation doping

To improve the conductivity further, conducting polymers have been irradiated with x-rays, gamma radiation, and gamma and electron beams. When ionizing radiation interacts with polymer materials active species such as free radicals are produced, thereby initiating chemical reactions including crosslinking, chain scission, and grafting.



The usage of radiation technology compared to chemical one has the advantages of pureness, no chemical catalysts, wider applications, easy process and commercial production [9].

## 3. Measurement of electrical conductivity

There are few methods for determining the surface resistivity of a material using common techniques such as the four-point probe method and the Van der Pauw method.

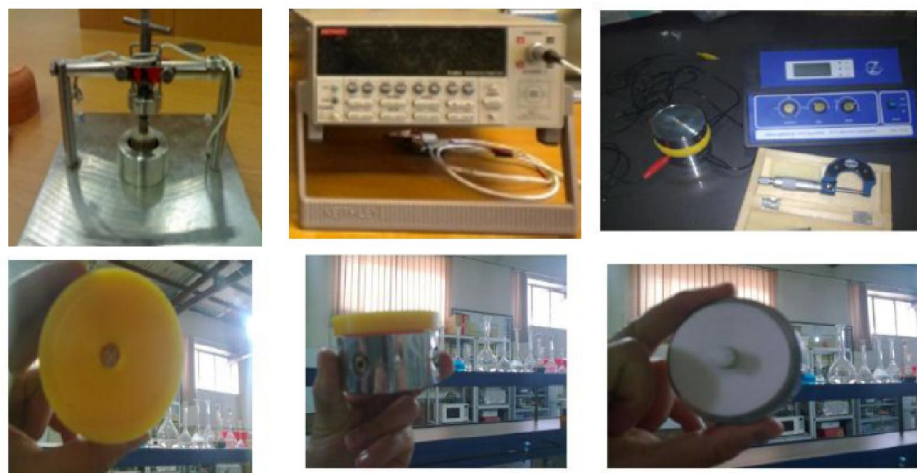
$$\sigma = \frac{\ln 2}{\pi d} \left( \frac{l}{V} \right)$$

### 3.1. Four-point probe method

Electrical conductivity measurements were performed by standard four-probe (4-point) method. A Keithley source meter and a Keithley electrometer were used as constant D.C. source and volt meter, respectively. Low temperature conductivity measurements were made using Sumitomo cryogenic, as shown in Figures 6.

The conductivity ( $\sigma$ ) was calculated from the relation (1). (1)

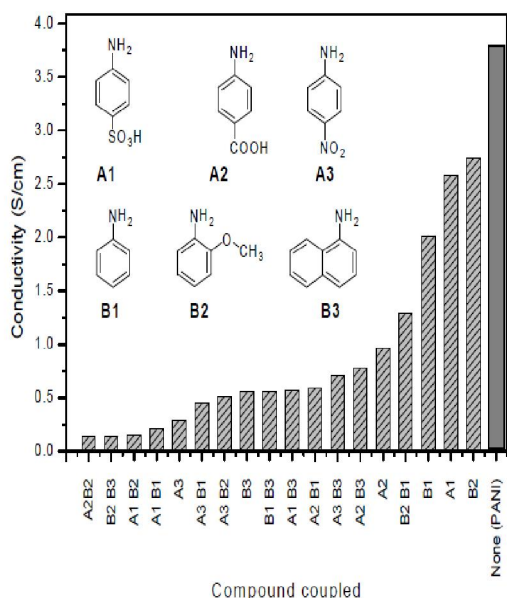
Where I, V and d are applied current, measured voltage and the thickness of the pellet, respectively [11].



## 4. Chemical procedures

### 4.1. Combinatorial coupling of diazonium salts with polyaniline

The low solubility of conducting polymers in most solvents makes them ideal to perform combinatorial chemistry reactions on the polymer. Recently, combinatorial reactions have been used to produce conjugated polymers with success. To extend the method to conductive polymer modification, diazonium coupling with polyanilines was chosen as synthetic method (Figure 7.), the decrease in conductivity is only of one order of magnitude. Such decrease is a reasonable trade-off for the improved solubility [10].



### 4.2. Composite formation

The first and the most widely used conducting polymeric systems are the composites in which an insulating polymer matrix is filled with a particulate or fibrous conductive fillers such as a carbon or a metal to impart high conductivity. Applications for such composites are wide spread, these are used for interconnections, printed circuit boards, encapsulations, die attach, heat sinks, conducting adhesives, electromagnetic interference (EMI) shielding, electrostatic discharge (ESD), and aerospace engineering. into account, the following aromatic amines were chosen for a first trial. It is possible to couple type an amines (non activated) with type B amines (activated) to produce azo dyes terminated in  $-NH_2$ . These azo dyes could be diazotized and coupled with PANI. The effectiveness of the diazonium salts coupling to PANI was tested.

As the aspect of chemical industries such as corrosion fields, composites of polyaniline, have been extensively used as anticorrosive coatings on metals. However pure coatings of polyaniline and its derivatives suffer from poor mechanical properties and adhesion strength. To improve the anticorrosive efficiency, mechanical properties and adhesion strength, polyaniline composites were prepared and applied on various metals for corrosion protection. Composite materials nowadays play an increasingly important role due essentially to their lighter weight and better corrosion resistance [10].

#### 4.2.1. Conducting polymer composite of multiwall carbon nanotubes filled-polyaniline

Tubular composite of protonic acid doped polyaniline (PANI) with multi wall carbon nanotubes

(MWNT) can be synthesized by in situ chemical oxidation polymerization [11].

#### 4.2.1.1. Composite formation mechanism

The formation of tubular composites is believed to arise from the strong interaction between aniline monomer and MWNT. The interaction possibly comes from the  $\pi$ - $\pi$  electron interaction between MWNT and the aniline monomer. Such strong interaction ensures aniline monomer adsorbed on the surface of MWNT during the formation of tubular composite. MWNTs therefore serve as the template and the core during the formation of the tubular composites. Due to the random formation of MWNT bundles, there are some "special gaps" between individual MWNTs as shown in Figure 8 [12].

#### 4.2.2. Preparation methods of different polymer based conducting composites from polyaniline

The methods of preparation of polymer-conductive filler systems depend primarily on the type of polymer, its initial form and the properties of the conductive filler. All the methods of composite preparation are discussed below:

##### 4.2.2.1. Melt mixing

This is a popular method of composite preparation. This process involves the mixing of different components with a polymer at a temperature beyond the melting point of the polymer. The melt mixing procedure has also been successfully employed to form elastomer-PANI composites.

##### 4.2.2.2. Mill mixing

This method is based on the incorporation of filler along with other ingredients into the rubber matrix in an open mill or internal mixer.

##### 4.2.3. Solution/dispersion mixing

This method involves the dissolution/dispersion of PANI and a matrix polymer either in the same solvent or in a different solvent, stirring of the mixture and finally drying out of the solvent.

##### 4.2.4. Composite preparation through in situ and/or graft polymerization

This method involves either: (a) preparation of both

PANI and the counterpart of the composite simultaneously in the same medium; or (b) dissolution/dispersion of the counterpart of the composite in a suitable solvent/water and polymerization of aniline in that medium; or (c) dissolution/dispersion of PANI in a suitable solvent/water and preparation of the counterpart of the composite in that medium.

##### 4.2.5. Composite preparation through electrochemical polymerization

This method involves the dispersion of the counterpart of the composite either in water or in a solvent containing aniline, acid or dopant and potential cycling is then repeated at the working electrode.

##### 4.2.6. Composite preparation through thermal reflux method

Pd-PANI composite has been prepared by the thermal reflux method, where the reaction mixture containing  $\text{PdCl}_2 \cdot 5\text{H}_2\text{O}$  and aniline in methanol/water (1/1.5) was refluxed for 3 h at a temperature of 50 °C.

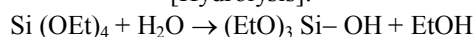
##### 4. 2.7. Composite preparation through sol-gel process

As discussed above, many researchers tried to find a solution for better processability of PANI such as mechanical blending, solution blending, electrochemical deposition, and chemical surface deposition. The solution blending method, one of the promising methods, is solubilizing polyaniline in a variety of solvents including non-polar solvents. With counter ions used for doping polyaniline.

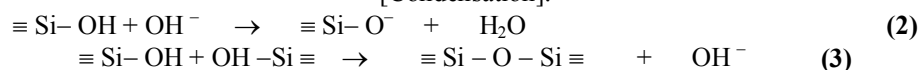
##### 4.2.7.1. Hybrid composite film formability

There are several factors affecting formation of silica gels, i.e., water contents, additives, gelation time, etc. but the most important factor of silica particle polymerization is the pH of the medium. Figure 8. illustrates the poly-merization of aqueous silica sol under different pH. The sol-gel process involves the hydrolysis-condensation reaction of TEOS including Eqs. (2, 3) [11].

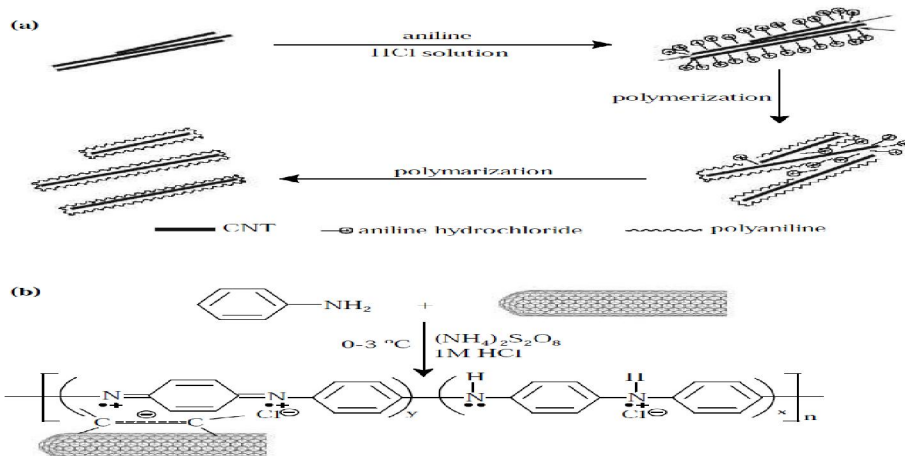
[Hydrolysis]:



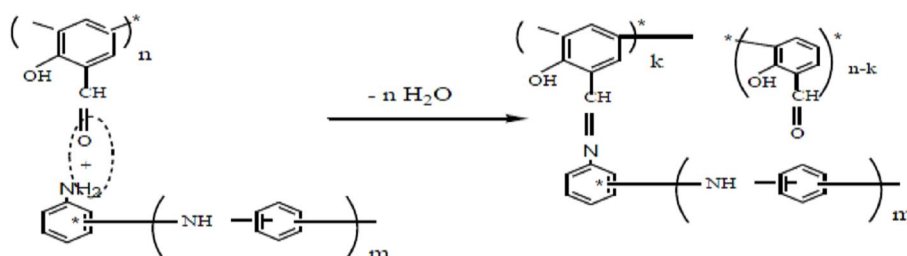
[Condensation]:







**Figure 8.** Schematic diagram of (a) the formation mechanism for tubular composites of MWNT and PANI, (b) in-situ polymerization and proposed composite interaction[11].

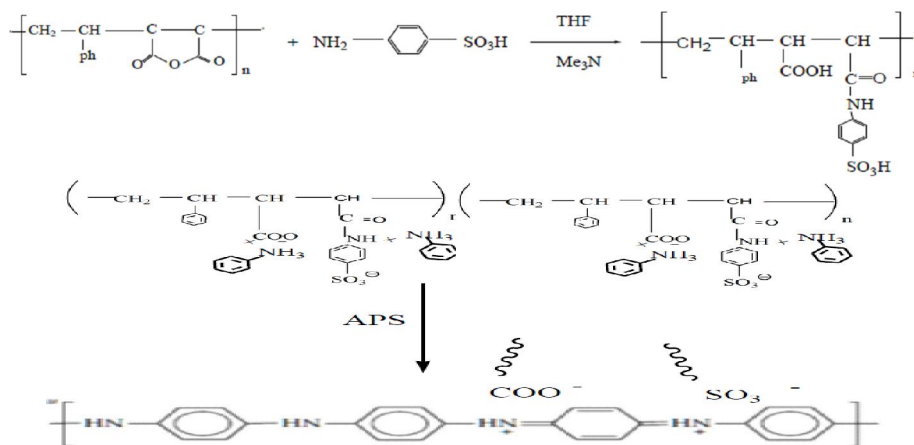


**Figure 9.** The preparation of graft-copolymer – copolyanilinehydroxybenzaldehyde (CAHB) has been carried out by joint condensation of oligoaniline(OA) & oligoaldehyde (OAHB) containing active amine & aldehyde groups respectively[13].

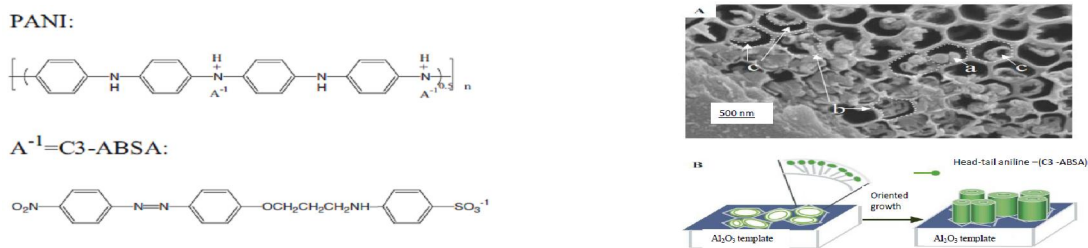
#### 4.2.8. Template polymerization

One of the most effective and simple techniques of nanostructure formation is template synthesis. In this synthesis the desired material with the required shape is

synthesized within the pores of a template and the template is then dissolved, leaving the material with the shape of the pores of the template. The template method has been used both for chemical and electrochemical polymerization in order to obtain conducting polymer nanotubes. Template-based methods have attracted great attentions as a viable technology enabling to manipulate a length and a diameter of nanowires (Figure10).

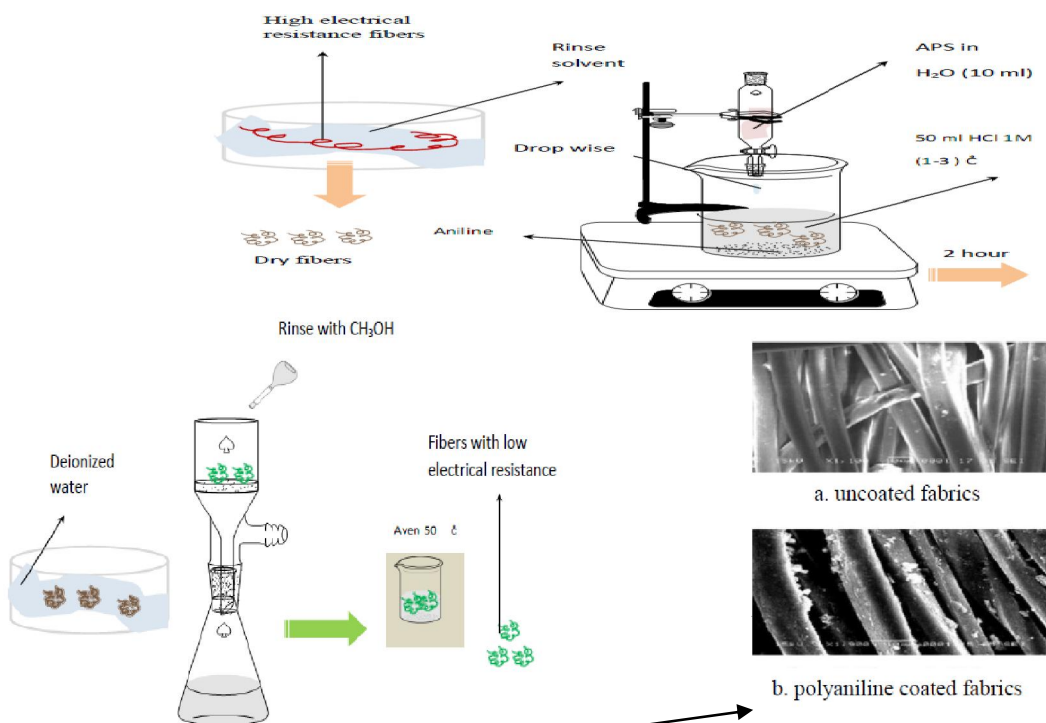


**Figure 10.** Synthesis route of PSMA & template [16]



Recently, various approach has veloped to synthesis PANI in the presence of matrix and template . The chemical and electrochemical oxidation of aniline followed by photonic doping has been reported for obtaining the polymer in conducting form. For practical applications, a conducting polymer must be cost-effective to synthesize, have good chemical and

electrical stability and be able to be easily processed. Many methods have been reported to obtain applicable materials. Compared with other methods, template polymerization methods require only regular apparatus, and the resulted conducting polymer materials are often orderly arranged. (Figures 11,12.)[16] .



**Figure 13.** Coating processes of conducting polyaniline on to a flexible substrate such as textile fabrics & SEM observation of polyaniline coated fabrics (a,b) ( SEM Figures from [16] ).

Since the discovery of electrical conductivity in ionic polymers, various ionically ICPs or polymer electrolytes have been prepared for a wide range of applications. The most interesting property of ICPs is their high (almost metallic) conductivity, which can be altered by simple oxidation or reduction and also by bringing the material into contact with different compounds.

The first and most widely used conducting polymeric systems were composites in which an insulating polymer matrix was filled with particulate or

fibrous conductive filler, such as a carbon or metal, to impart high conductivity. Applications for such composites are widespread; these composites are used for interconnections, printed circuit boards, encapsulations, die attach, heat sinks, conducting adhesives, electro-magnetic interference (EMI) shielding, electrostatic discharge (ESD) and aerospace engineering. Unfortunately, these conductive fillers will impart heavy weight, poor surface finish, poor mechanical properties and easy oxidative degradation to the end product.

The preparation of PANI composites with various materials has received great attention because of their unique properties and applications in various electrical devices. However, the main problem associated with the effective utilization of all intrinsically ICPs (ICPs), including PANI, is inherent in their lower level of conductivity compared to metal and their infusibility and poor solubility in all available solvents. Polymer composites containing PANI (matrixes) have received much attention because of the resultant combination of improved processability and fairly good mechanical properties coupled with good conductivity [16].

#### 4.2.9. Polyaniline nanofibers

Nanofibers with diameters of tens of nanometers appear to be an intrinsic morphological unit that was found to “naturally” form in the early stage of the chemical oxidative polymerization of aniline. In conventional polymerization, nanofibers are subject to secondary growth of irregularly shaped particles, which leads to the final granular agglomerates. The key to producing pure nanofibers is to suppress secondary growth [17].

### 5. Application aspects

#### 5.1. Conductive polymers for corrosion protection

The potential of conducting polymer coating for corrosion protection is a topic of current controversy. In general, efficacy of conducting polymers very much depends on how they are applied and on the conditions of the corrosion experiment, i.e. depending on the exact conditions a conducting polymer may have excellent protection capability or may lead to a disastrously enhanced corrosive attack (Figure 14) [18].

#### 5.2. Coating of conducting polyaniline

Coating of conducting polyaniline on to a flexible substrate such as textile fabrics and sheets can retain the flexibility of the fabrics and the electrical conductivity of the ICPs. The electrical conductivity of polyaniline coated textile structures can be assorted by varying the concentrations of monomer, dopant, oxidizing agent and the polymerization parameters such as time and temperature. However, the amount of polymer deposition i.e. thickness of the coated layer can directly influence the fabric electrical conductivity. The coating of such conducting polymer-metal nanocomposite on the substrates typically requires more than two steps including purification steps:

##### 5.2.1. Coating of the substrates with a conductive polymer

##### 5.2.2. Application of metal nanoparticles onto the conducting polymer shells.

It was reported that conducting polymer-noble metal nanocomposites can be synthesized by a one-step chemical oxidative polymerization using metal salts as an oxidant. It was demonstrated that chemical oxidative polymerization using metal salts such as hydrogen

tetrachloroaurate(III), silver nitrate ( $\text{AgNO}_3$ ), palladium(II) chloride ( $\text{PdCl}_2$ ), which act both as an oxidant and as a source of metal atoms, yielded well-dispersed metal nanoparticles in/on bulk ICPs [19].

Henry et al. and Fujii et al. [17] suggested that  $\text{PdCl}_2$  acts as an efficient oxidant for pyrrole to form PPy-Pd composite in aqueous media (Figure 15).

The solution processability and film-forming capability are of critical importance for the applications of a polymer. Since, polyaniline is insoluble in water, it has been known to have poor water processability, likely due to the irregularly shaped micron-sized morphology. Therefore, an adduct such as a water soluble polymer [e.g., poly(N-vinylpyrrolidone), PVP] is needed to form a polyaniline colloidal dispersion. However, polyaniline synthesized by either interfacial polymerization or rapidly mixed reactions exhibit excellent water dispersibility due to its uniform nanofibrillar morphology. For example, when purified by dialysis or centrifugation, polyaniline nanofibers readily.

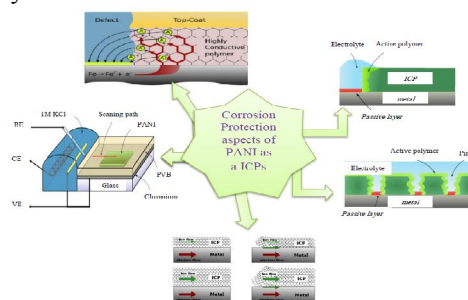


Figure 14. Conductive polymers for corrosion protection (original Figures from [18].)

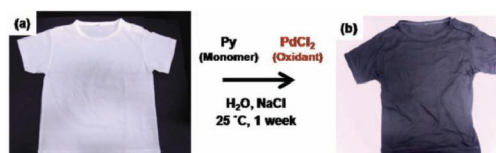


Figure 15. Digital photographs of T-shirt (Cotton 100 %) before (a) and after (b) PPy-Pd nanocomposite coating [17].

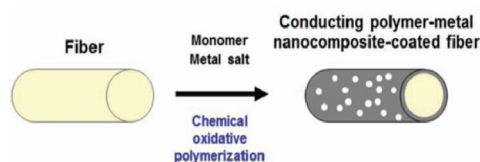


Figure 16. facile syntheses of fibers coated with conducting polymer-noble metal nanocomposites in aqueous media disperse in water without any adduct. Casting such dispersion onto a substrate, a mat of a random nanofiber network is obtained. (Figure 15) [17].

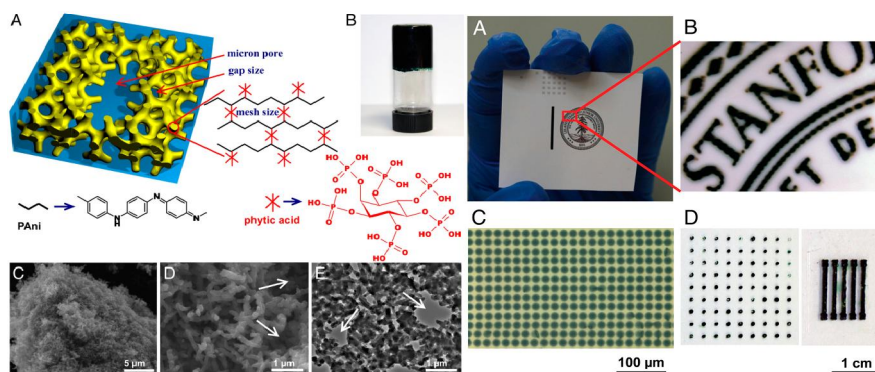
#### 5.3. Conductive polymer hydrogels

Hydrogels are polymeric networks that have a high

level of hydration and three-dimensional (3D) microstructures bearing similarities to natural tissues. Hydrogels based on conducting polymers [e.g., polyaniline (PANI),] combine the unique properties of hydrogels with the electrical and optical properties of metals or semiconductors thus offering an array of features such as intrinsic 3D microstructured conducting frameworks that promote the transport of charges, ions, and molecules. Conducting polymer hydrogels provide an excellent interface between the electronic transporting phase (electrode) and the ionic-transporting phase (electrolyte), between biological and synthetic systems, as well as between soft and hard materials. As a result, conducting polymer hydrogels have demonstrated great potential for a broad range of applications from energy storage devices such as biofuel cells and supercapacitors, to molecular and bioelectronics and medical electrodes (Figures 17,18) [20].

Other potential applications of these ICPs are in

chemical, biochemical and thermal sensors, artificial nerves, drug release systems, antistatic clothing, ion exchange membranes, electromechanical actuators and 'smart' structures. Interest in ICPs has its origins in the possible commercial applications of these materials. The commercial applications are based on the promise of a novel combination of light weight, processibility and electrical conductivity. Some of conducting polymer can change their optical properties on applications of current or voltage and therefore may find useful applications as heat shutter and light emitting diode (LEDs). These polymers have following important applications and are used in Electrostatic materials Molecular electronics Conducting adhesives Electrical displays, Electromagnetic shielding Chemical biochemical and thermal sensors, Printed circuit boards Rechargeable batteries and solid electrolytes, Artificial nerves Drug release systems, antistatic materials, Antistatic clothing.



### 6.7. Other applications of ICPs

Optical computers, Piezoceramics Ion exchange membranes, Active electronics (diodes transistors) Electromechanical actuators, Aircraft structures 'Smart' structures, Switches, Welding of plastics, Corrosion protection, Loudspeakers.

### 6. Conclusions

This review has attempted to outline various aspects of polyaniline (PANI) as intrinsically conducting polymers (ICPs). All considered features present strengths and weaknesses for any specific application some advantages or problems need to be evaluated and some of fitted literatures of this article; fundamental concepts, chemical structure of monomers, kind of dopants, procedures & environment for polymerization are required for obtaining high quality composites represented.

The investigations of PANI's composite materials are an active exploration of the research because of its low cost, easy polymerization of its monomers, and unique properties. Important progress in the

preparation of its composites and application of PANI has been reported consistently in the literature within recent years.

The choice of dopants, kind of functional groups on monomer derivatives, chemical structure of other elements such as grafts or template, reactant concentrations, ratio oxidant/monomer and polymerization conditions such as ultrasonication, are important to obtain a regular PANI structure with high possible molecular mass, size/nanosize of particles or immixing with other elements in its composites/nanocomposites. Low cost, easy polymerization and improvement performance of PANI makes these polymers the most promising composite materials for application in different industrial fields. New procedures of alternative polymerization for blending that can improve the properties of PANI composites, should promote future development of PANI in different application fields.

PANI literatures not only have been widely studied as research field, but also education regards especially in the view point of audience motivation. However, in this



work some aspect that would enhance performance would be to overcome the educational broadening that is often observed. More recently, an increasing number of papers on ICPs and PANI composites have been produced. PANI is a competitive element in conducting polymers for the stability and low cost preparation of the imprinted composites, compared with other conductive polymeric products. Today there are already conducting composites commercially available for application in various devices. However, the main problem associated with the effective utilization of all intrinsically conducting polymers (ICPs), including PANI, is inherent in their lower level of conductivity compared to metal and their infusibility and poor solubility in all available solvents (weak processability). Polymer composites containing PANI (matrixes) have received much attention because of the resultant combination of improved processability and fairly good mechanical properties coupled with good conductivity. In other review literatures, education aspects, have not yet been thoroughly attended. Enough regards in these areas are only just beginning to emerge and there are several potential aspects to be explored that could produce progress in the next few years in chemical education fields.

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