

Chemical Preparation of Conducting Polyfuran/Poly(2-chloroaniline) Composites and Their Properties: A Comparison of Their Components, Polyfuran and Poly(2-chloroaniline)

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ABSTRACT: Conductive homopolymers and composites of poly(2-chloroaniline) (P2ClAn) and polyfuran (PFu) were synthesized chemically in hydrous and anhydrous media, and their properties were investigated. The polymers and composites were characterized by Fourier infrared spectroscopy, ultraviolet-visible absorption spectroscopy, thermogravimetric analysis, differential scanning calorimetry, scanning electron microscopy, magnetic susceptibility, and conductivity measurements. It was found that the PFu/P2ClAn composite is thermally more stable than both the P2ClAn/PFu composite and the homopolymers. It was determined from Gouy scale measurements that conducting mechanisms of homopolymers and composites are polaron and bipolaron in nature. It was observed that the conductivity

and magnetic susceptibility values changed with a changing amount of the guest polymer in the prepared composites. The conductivity (3.21×10^{-2} S/cm) of the P2ClAn/PFu (55.8% m/m) composite was found to be higher than the conductivities of both homopolymers ($\sigma_{\text{PFu}} = 1.44 \times 10^{-5}$ S/cm; $\sigma_{\text{P2ClAn}} = 1.32 \times 10^{-3}$ S/cm). It was determined that the composites synthesized had different conductivities and morphological and thermal properties from changing synthesis order. © 2003 Wiley Periodicals, Inc. *J Appl Polym Sci* 88: 2924–2931, 2003

Key words: composites; conducting polymers; conjugated polymers

INTRODUCTION

Conducting polymers have many applications as electronic devices, batteries, and sensors in scientific and technological areas.^{1–3} Polyaniline, polypyrrole, and polythiophene and their derivatives are important in these situations because of their good conductivity and chemical stability.^{4–6} Among doped polyconjugated polymers, polyfuran has been one of the less studied conducting materials because of the difficulties in synthesizing it and because of its low conductivity.^{7,8} It may be difficult to polymerize furan because it has a higher potential of oxidation than other conducting polymers. It has low electrical conductivity as a result of the low level of conjugation in its polymeric chains.⁹

One of the disadvantages in the processing of conducting polymers for technological applications is their poor solubility in the majority of solvents. This solubility can be enhanced by preparing derivatives of

the conducting polymers.^{10,11} To make systematic changes in the properties (e.g., conductivity, solubility, processibility) of the conducting polymers, various methods have been employed: (1) chemical methods, such as chemical modification of the conducting polymer, preparing copolymers or composites^{12,13}; and (2) physical methods, such as blending the conducting polymer with one or more other materials^{14,15} or doping with a suitable dopant that plays the role of plasticizer.¹⁶

Recently, great attention has been paid to the preparation of a conducting polymer composite^{17,18} because with this method it is possible to prepare high-quality polymers, including those with good electrical properties. With this purpose, most of the copolymers and composites of polyaniline and polyfuran and their derivatives already have been prepared.^{6,19,20}

In this study, in order to modify the properties of poly(2-chloroaniline) and polyfuran, the aim was to synthesize conducting composites of these two polymers that had not been previously investigated. PFu/P2ClAn and P2ClAn/PFu composites were prepared, changing the synthesis order of the guest polymer in composites of both homopolymers that needed different synthesis conditions. The effects of variation in synthesis order on the properties of the composites

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obtained were investigated. The PFu:P2ClAn (1:1) mechanical mixture of both homopolymers was prepared, and their properties were compared with those of the PFu/P2ClAn and P2ClAn/PFu conducting composites. The obtained composites and homopolymers were characterized by Fourier transform infrared spectroscopy (FTIR), ultraviolet-visible absorption spectroscopy (UV-vis), thermogravimetric analysis (TGA), differential scanning calorimetry (DSC), thermal analysis, scanning electron microscopy, and conductivity and magnetic susceptibility measurements.

EXPERIMENTAL

Materials

All chemicals were obtained from Aldrich. 2-Chloroaniline and furan were distilled in vacuum under a nitrogen atmosphere prior to use. Ammonium persulfate $[(\text{NH}_4)_2\text{S}_2\text{O}_8]$, antimony(III) chloride (SbCl_3), chloroform, hydrochloric acid, *N,N*-dimethylformamide (DMF) and diethyl ether were used as received.

Synthesis of P2ClAn and PFu homopolymers

In 100 mL of 1.5M HCl, 8.76 mmol of 2-chloroaniline was dissolved. The temperature of solution was maintained at 2–5°C. To the monomer solution was added dropwise another solution of 17.5 mmol of $(\text{NH}_4)_2\text{S}_2\text{O}_8$ in 100 mL of 1.5M HCl. The polymer solution was stirred for 24 h. The pristine polymer was collected by filtration and then washed with 1.5M HCl, distilled water, and diethyl ether until the filtrate was clear; then it was dried in a vacuum oven at 70°C for about 24 h.

In a nonaqueous media (CHCl_3), 13.3 mmol of furan was polymerized at 20°C using SbCl_3 as an oxidant (ratio of oxidant to monomer of 1.3 : 1). Polyfuran was washed with chloroform and dried in a vacuum oven at 70°C.

Synthesis of PFu/P2ClAn conducting composite

For synthesis of the PFu/P2ClAn composite, a certain amount of PFu powder was dispersed in a 1.5M HCl medium, with stirring at 2–5°C. Then $(\text{NH}_4)_2\text{S}_2\text{O}_8$ was added to the medium and stirred under an N_2 atmosphere. To the dispersed polymer solution was added a dropwise solution of 2-ClAn in 1.5M HCl. After polymerization for 24 h, the composite was collected and washed with 1.5M HCl. Finally, the composite was dried in a vacuum oven at 70°C for 24 h. The quantity of P2ClAn in the composite was calculated from the total mass of the composite. PFu/P2ClAn composites of varied percentages of P2ClAn were prepared, maintaining constant ratios of salt to monomer.

Synthesis of P2ClAn/PFu conducting composite

A certain amount of P2ClAn powder was dispersed in CHCl_3 . Then SbCl_3 was added to medium and stirred at 20°C. To this solution furan monomer was added drop by drop. After 24 h the composite was filtrated and washed with CHCl_3 . The product was dried in a vacuum oven at 70°C. The amount of PFu was calculated from the total mass of the composite. P2ClAn/PFu composites were synthesized in which the percentage of PFu varied while maintaining ratios constant.

Characterization

FTIR spectra of the polymer samples were recorded with a Mattson 1000 model spectrophotometer employing the KBr pellet technique. The UV-vis spectra were taken in DMF using a Unicam UV-2 model spectrophotometer. The conductivities of the synthesized polymers were measured using the four-probe technique. The polymer samples were made into pellets, and their conductivity levels were measured using a Nippon NP-900 multimeter. TGA thermograms were recorded with a Rigaku Var 2-22E2 thermal analysis system at a heating rate of 10°C/min in a nitrogen atmosphere up to 1000°C. The DSC measurements were carried out in a nitrogen atmosphere at a heating rate of 10°C/min between 0°C and 600°C using a SETARAM DSC 131 model calorimeter. Scanning electron microscopy (SEM) micrographs of the polymers in powder form were taken on a SEM (Jeol, model JEM 100 CX II). Magnetic susceptibility measurements were carried out with a Sherwood Scientific model MKI Gouy scale, using a procedure reported elsewhere.²⁰

RESULTS AND DISCUSSION

The conductivities and magnetic susceptibility values of the composites containing different percentages of P2ClAn are given in Table I. As can be seen in Table I, the conductivities of P2ClAn and PFu were determined as 1.32×10^{-3} and 1.44×10^{-5} S/cm, respectively. It can also be seen that the conductivity of an PFu/P2ClAn composite increased with an increasing yield percentage of P2ClAn. Once the composite reached 32% P2ClAn, additional increases of P2ClAn did not change the conductivity, which then remained nearly constant. In addition, the conductivity of this composite was close to that of a PFu:P2ClAn (1:1) mechanical mixture.

The magnetic susceptibility data of the polymers also are given in Table I. It was determined that the magnetic susceptibility values of the homopolymers, composites, and (1:1) mechanical mixture had diamag-

TABLE I
Conductivity and Gouy Balance Measurements of PFu/P2ClAn Composites

Polymer	Yield of P2ClAn in composite (m/m %)	Conductivity (S/cm)	Magnetic susceptibility (μ_{eff} BM)*
PFu/P2ClAn	1.0	3.44×10^{-5}	-43
PFu/P2ClAn	11	4.02×10^{-5}	-43
PFu/P2ClAn	19	1.93×10^{-4}	-42
PFu/P2ClAn	32	2.57×10^{-3}	-13
PFu/P2ClAn	46	9.77×10^{-3}	-40
PFu/P2ClAn	59	1.33×10^{-3}	-38
PFu/P2ClAn 1:1 mechanical mixture	—	3.80×10^{-3}	-37
PFu	—	1.44×10^{-5}	-51
P2ClAn	—	1.32×10^{-3}	-37

* μ_{eff} : effective magnetic moment; BM: Bohr magneton.

netic properties, that is, their conducting mechanisms were bipolaron in nature.²¹

The conductivity and magnetic susceptibility values of the prepared P2ClAn/PFu composites that had a changing order of synthesis of the guest polymer are given in Table II. As can be seen in Table II, the conductivity of the composites that were 47.0% and 55.8% PFu were higher than that of the PFu, the P2ClAn, and the 1:1 mechanical mixture. An overall look at the tabulated conductivity values reveals that the conductivities of the polymer samples tended to change according to the order of synthesis. Similar results were observed for the polyaniline/polypyrrole and polyaniline/polythiophene systems in previous electrochemical studies.^{20,22}

Magnetic susceptibility data of the polymers shifted to positive values with an increasing amount of PFu. This shows that polaron groups in composite structure increase with an increasing amount of PFu.²³ Based on this observation, it was concluded that P2ClAn/PFu is not simply a mechanical mixture, that is, P2ClAn/PFu is a composite. It was determined that both the conductivity and magnetic susceptibility values of the PFu/P2ClAn and P2ClAn/PFu conducting composites changed with varying synthesis order.

Figure 1 shows a comparison of the FTIR spectra of conducting polymers such as P2ClAn, PFu, PFu/P2ClAn, and the PFu:P2ClAn (1:1) mechanical mixture. When the spectra of PFu/P2ClAn [Fig. 1(a)] are investigated, the characteristic peaks corresponding to both homopolymers (PFu, P2ClAn) were seen and the shifts in wavenumbers of these peaks were determined. The frequency of bands seen at 791–746 cm^{-1} corresponding to C—H out-of-plane bending of the furan ring²⁴ [Fig. 1(b)] had shifted to 810–752 cm^{-1} in the composite. The 1580 and 1503 cm^{-1} bands belonging to aromatic C=C stretching vibrations of the quinonoid and benzenoid rings at the P2ClAn spectrum [Fig. 1(c)]²⁵ had shifted to, respectively, 1593 and 1497 cm^{-1} in the composite. The C—H stretching bands (1305 cm^{-1}) of P2ClAn can be seen at 1339 cm^{-1} in the composite. The bands at 1214 and 1142 cm^{-1} correspond to C—C (or C—N) stretching and, in the plane C—H bending modes, the shift to 1250 and 1160 cm^{-1} , respectively, in composite.²⁶ The FTIR spectra [Fig. 1(d)] of PFu:P2ClAn mechanical mixture show bands similar to those of P2ClAn. A similar situation can also be observed in conductivity and magnetic susceptibility results of the PFu:P2ClAn mechanical mixture. The FTIR spectra of the P2ClAn/PFu composite, P2ClAn,

TABLE II
Conductivity and Gouy Balance Measurements of P2ClAn/PFu Composites

Polymer	Yield of PFu in composite (m/m %)	Conductivity (S/cm)	Magnetic susceptibility (μ_{eff} BM)*
P2ClAn/PFu	7.00	1.32×10^{-3}	-37
P2ClAn/PFu	11.0	1.44×10^{-3}	-13
P2ClAn/PFu	41.2	1.52×10^{-3}	+6
P2ClAn/PFu	47.0	2.02×10^{-2}	+15
P2ClAn/PFu	55.8	3.21×10^{-2}	+18
P2ClAn/PFu 1:1 mechanical mixture	—	3.80×10^{-3}	-37
PFu	—	1.44×10^{-5}	-51
P2ClAn	—	1.32×10^{-3}	-37

* μ_{eff} : effective magnetic moment; BM: Bohr magneton.

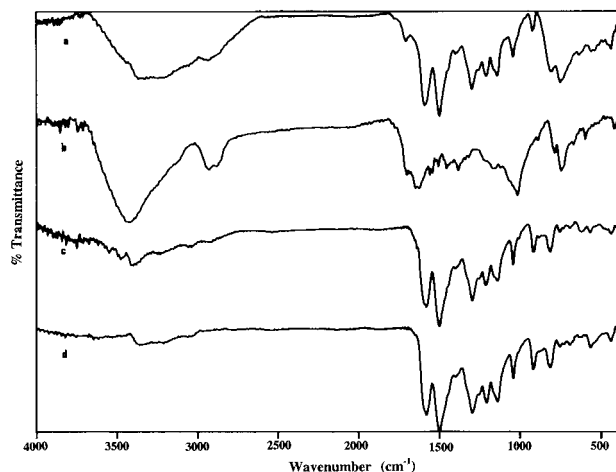


Figure 1 FTIR spectra of polymers: (a) PFu/P2ClAn, (b) PFu, (c) P2ClAn, (d) PFu:P2ClAn 1:1 mechanical mixture.

PFu, and the mechanical mixture are given in Figure 2. If the spectra are investigated, differences at the bands at 1300 cm^{-1} and shifts at other bands can be seen. The FTIR spectral characteristics of the composites were found to be different from those of the homopolymers, but the differences were not as distinct as those obtained with conductivities and TGA results.

The UV-vis spectra of polymeric samples were recorded at room temperature and are shown in Table III. Two absorption bands can be observed in the UV-vis spectra of the polymers (Fig. 3). The first absorption is assigned to the $\pi \rightarrow \pi^*$ transition of the polymer-backbone benzenoid rings and the second absorption to the $\pi \rightarrow \pi^*$ transition of the diamine groups in the quinoid rings.^{27,28} The shifts in spectra of the composites were observed according to their P2ClAn. The first and second absorption bands in the PFu/P2ClAn composite shifted to a long wavelength. In the P2ClAn/PFu composite the first band shifted to

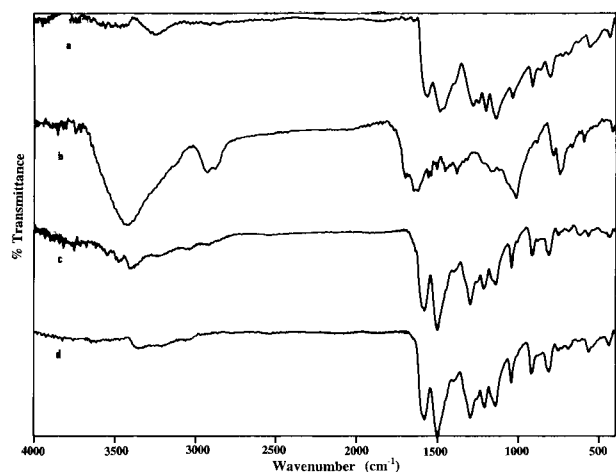


Figure 2 FTIR spectra of polymers: (a) P2ClAn/PFu, (b) PFu, (c) P2ClAn, (d) PFu:P2ClAn 1:1 mechanical mixture.

TABLE III
Absorption Spectral Data of Polymers

Polymer	λ_1 (nm)	λ_2 (nm)
P2ClAn	319	598
PFu/P2ClAn	320	599
P2ClAn/PFu	317	607
PFu:P2ClAn 1:1 mechanical mixture	321	602

a short wavelength, whereas the second band shifted to long wavelengths. The absorbance wavelengths of the PFu:P2ClAn (1:1) mechanical mixture were close to those of P2ClAn. The UV-vis spectrum of PFu could not be taken out because of its insolubility in common solvents. The absorbance wavelengths of PFu/P2ClAn were close to those of P2ClAn, results that are in accord with the conductivity measurements (Table I). The second band, corresponding to the polaron structures and arising from the charge transfer from the benzenoid rings, exhibited a shift to long wavelengths.²⁸ This shift shows an enhanced conjugation in polymer backbone, a result also in accordance with the increasing conductivity. Similarly, the conductivity of the P2ClAn/PFu composite was found to be higher than that of P2ClAn (Table II).

The DSC measurements were carried out in order to determine the thermal transitions in the polymers and composites. The DSC curve of P2ClAn is shown in Figure 4. An endothermic peak at 133°C can be observed because of the removal of water molecules present in P2ClAn.²⁹ The second endothermic peak, at 190°C , indicates the loss of dopant anions bound to the polymer chain.³⁰ The exothermic peak at 370°C suggests interchain crosslinking.^{31,32} The peak observed at 496°C corresponds to the degradation of the polymer.

If the DSC curve of PFu is investigated (Fig. 5), three endothermic transitions (79°C , 115°C , and 250°C) can

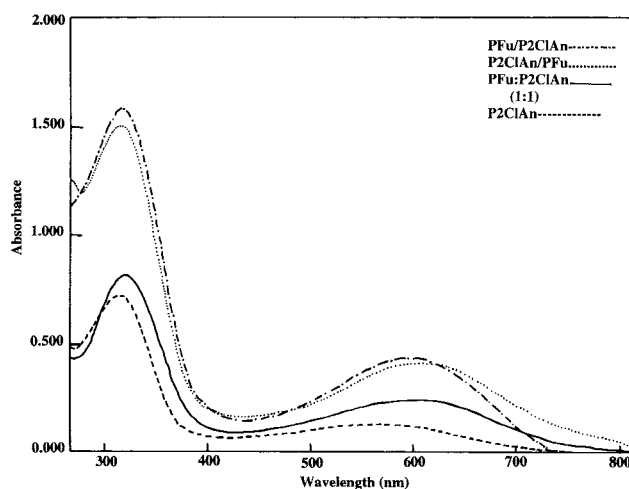


Figure 3 UV-vis spectra of polymers.

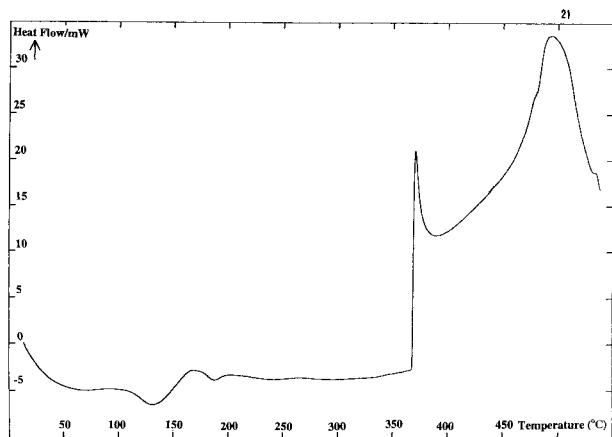


Figure 4 DSC curve of P2ClAn.

be seen. The peaks seen at 79°C and 115°C indicate removal of units with low molecular weights such as monomers and solvents present in PFu.³³ The transition observed at 171°C may be described as the glass-transition temperature of PFu.²⁴ The peak at 250°C indicates the removal of dopant anions. The sharp peak observed at 400°C may be attributed to inter-chain crosslinking.

Three endothermic transitions, at 118°C, 194°C, and 305°C, can be observed in the DSC curve of PFu/P2ClAn (41:59 m/m %) composite (Fig. 6). The transitions at 118°C and 194°C indicate removal of low molecular weights such as monomers, moisture, and solvents absorbed in PFu and P2ClAn. The peak at 305°C indicates elimination of the dopant.

The DSC curve of the P2ClAn/PFu conducting composite (Fig. 7) is similar to that of PFu/P2ClAn composite. As can be seen in Figure 7, three endothermic peaks are present—peaks at 100°C and 162°C arising from the removal from the composite of units with low molecular weights and another endothermic peak at 274°C arising from the removal of dopant in the polymer matrix. The exothermic peak at 408°C corresponds to the degradation of the polymer.³⁴

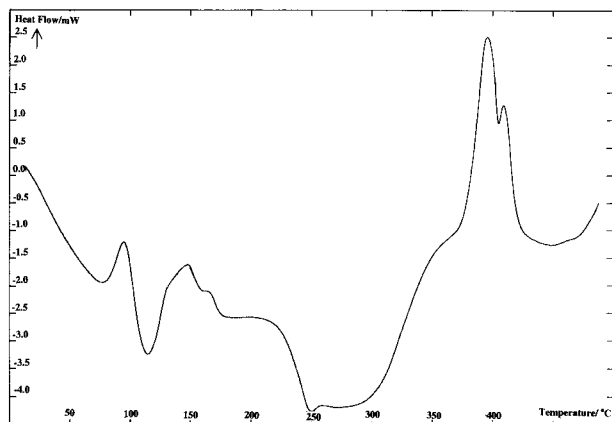


Figure 5 DSC curve of PFu.

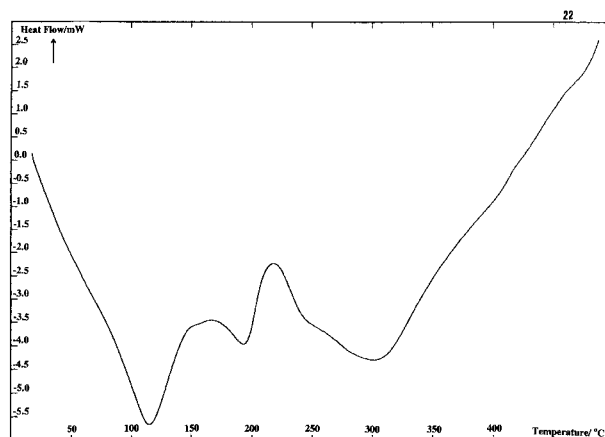


Figure 6 DSC curve of PFu/P2ClAn.

The DSC curve of the PFu:P2ClAn (1:1) mechanical mixture is shown in Figure 8. Three endothermic transitions can be observed, at 122°C, 187°C, and 296°C, whereas an exothermic transition can be seen at 413°C. The DSC curve of mechanical mixture is similar to those of the PFu/P2ClAn and P2ClAn/PFu composites, shown in Figures 6 and 7, respectively.

These results revealed that there is no chemical bonding (such as a copolymer) between polymers in composites (PFu/P2ClAn and P2ClAn/PFu). It can be concluded that PFu/P2ClAn and P2ClAn/PFu are composites.

The TGA curves of the homopolymers and composites are given in Figure 9 and the tabulated results in Table IV. As can be seen from Table IV, the three decomposition temperatures (T_i , T_m , T_f) of the polymers were different from each other. PFu shows decomposition in three steps. The first weight loss (114–273°C) indicates the loss of small units such as solvents and monomers in the polymers. The second weight loss, between 273°C and 409°C, indicates removal of the dopant anions from the polymer struc-

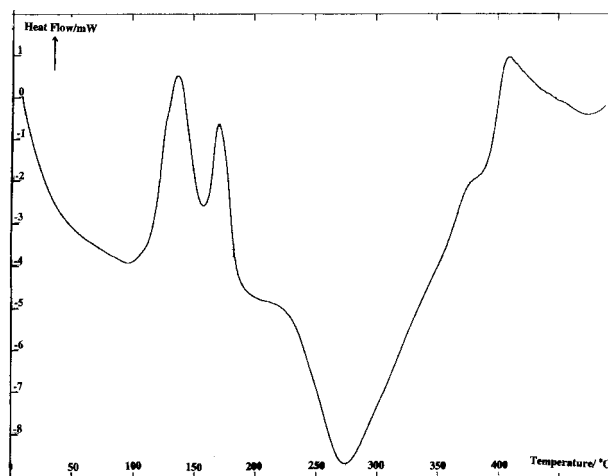


Figure 7 DSC curve of P2ClAn/PFu.

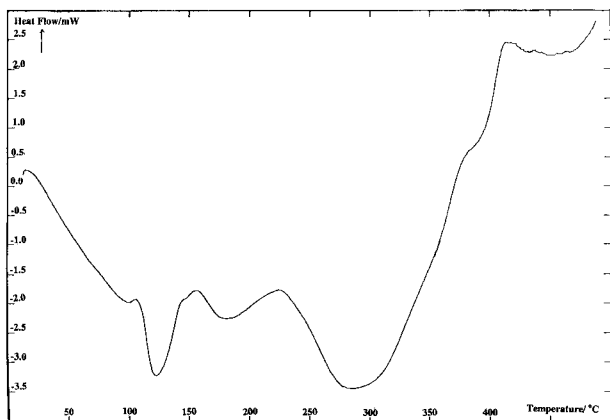


Figure 8 DSC curve of PFu:P2ClAn 1:1 mechanical mixture.

ture. The final step, at 518°C–568°C, shows degradation of the polymers.

It was determined that P2ClAn, the PFu:P2ClAn mechanical mixture, and composites show two-step weight loss. In the TGA thermograms of the polymers, the weight loss between 30°C and 100°C corresponded to the removal of water absorbing in the polymer matrix.³⁵

At the second decomposition temperature (136–464°C), the polymer chain structure decomposed after the elimination of the dopant acids from the polymer structure.³⁶ According to initial decomposition temperatures (T_i), PFu/P2ClAn composite had the highest decomposition temperature (255°C). The PFu/P2ClAn composite system prepared in the changing synthesis order was more thermally stable than the P2ClAn/PFu composite. Although P2ClAn/PFu had the highest conductivity, it also had lower thermal stability. These results are in accord with the results of the DSC. Moreover, from the decomposition temperatures it can be observed that the composites were thermally stable.

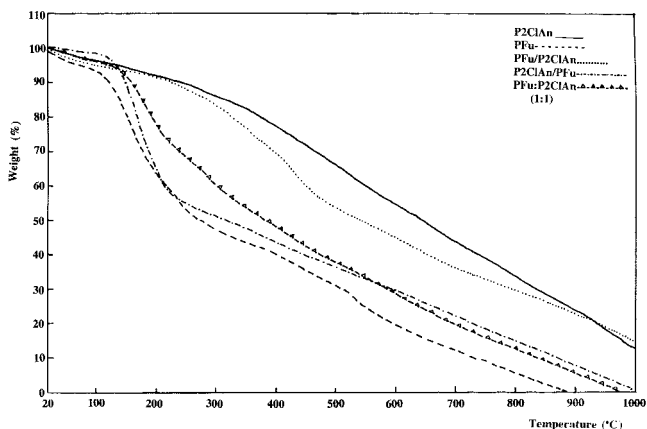


Figure 9 TGA thermograms of polymers.

TABLE IV
Results of TGA Analysis of Polymers

Polymer	Decomposition temperature (°C)		
	T_i^a	T_m^b	T_s^f
	114	181	273
	273	341	409
PFu	518	541	568
P2ClAn	177	275	373
PFu/P2ClAn	255	364	464
P2ClAn/PFu	136	173	227
PFu:P2ClAn 1:1 mechanical mixture	148	209	318

T_i^a : initial temperature; T_m^b : maximum decomposition temperature; T_s^f : final temperature.

The SEM micrograph of P2ClAn (Fig. 10) shows a granular and porous structure. The surface morphology of PFu can be seen to have two different structures (Fig. 11). The SEM micrograph of PFu shows a non-porous and uniform structure in the under layer and a granular and spongelike structure on the upper surface. The SEM micrograph of PFu/P2ClAn (Fig. 12) shows a spongelike and vessel-like structure, whereas that of P2ClAn/PFu (Fig. 13) shows a disorganized spongelike structure. It can be seen that the surface morphologies of PFu and P2ClAn are different from each other. This difference in the morphology of the

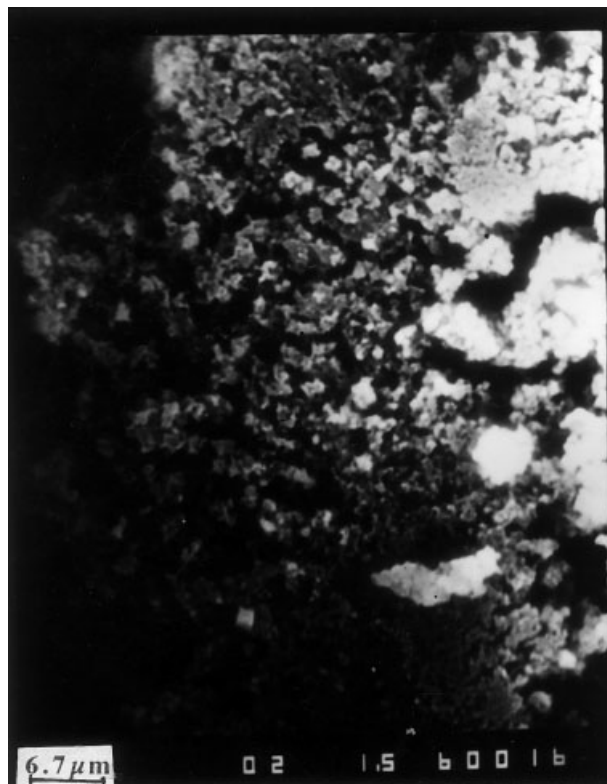


Figure 10 SEM micrograph of P2ClAn (magnification 1500X, bar = 6.7 μm).



Figure 11 SEM micrograph of PFu (magnification 800X, bar = 12.5 μm).

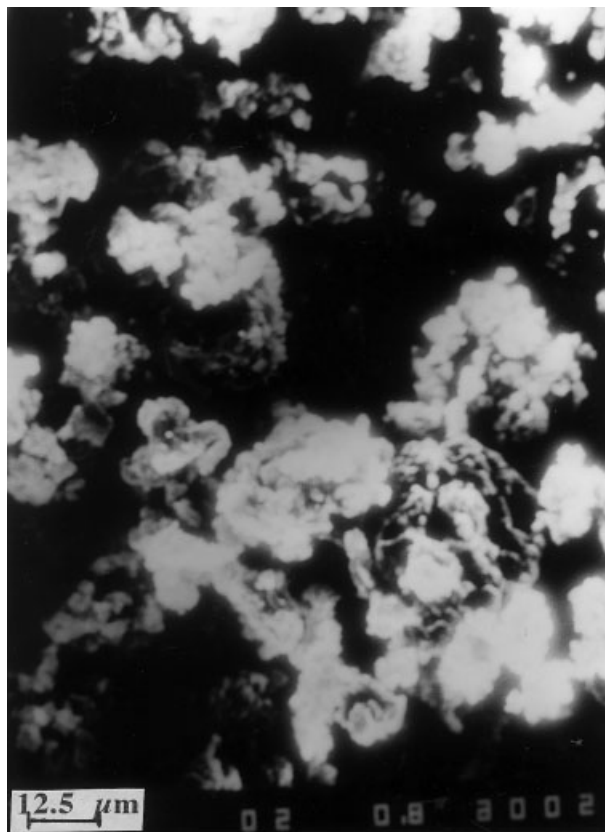


Figure 13 SEM micrograph of P2ClAn/PFu (magnification 800X, bar = 12.5 μm).



Figure 12 SEM micrograph of PFu/P2ClAn (magnification 800X, bar = 12.5 μm).

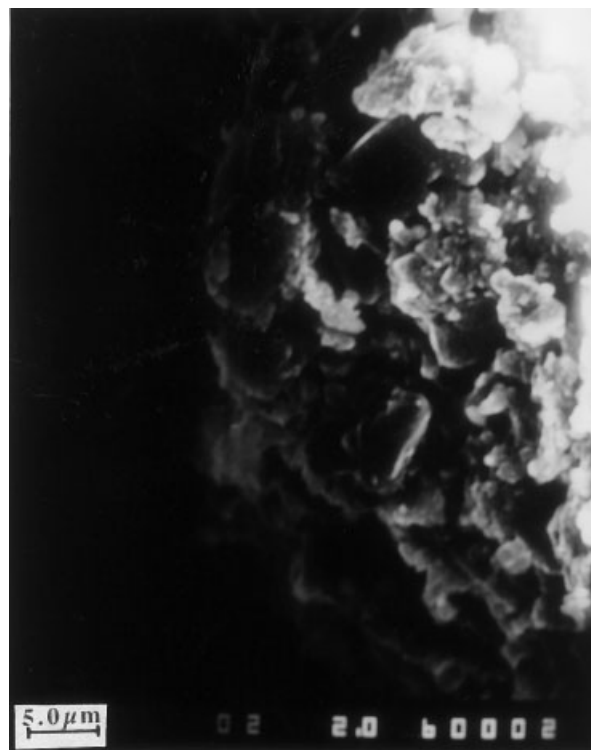


Figure 14 SEM micrograph of PFu:P2ClAn (1:1) mechanical mixture (magnification 2000X, bar = 5.0 μm).

polymers greatly depends on the types of anions and monomers.³⁷ So, the surface morphology of a polymer influences its conductivity. The SEM micrographs of PFu/P2ClAn and P2ClAn/PFu are different from homopolymers. The SEM micrograph of the PFu:P2ClAn (1:1) mechanical mixture (Fig. 14) looks like both PFu and P2ClAn structures. Moreover, the PFu/P2ClAn and P2ClAn/PFu composites are rather different from that of the PFu:P2ClAn (1:1) mixture. From the SEM micrographs it can be concluded that PFu/P2ClAn and P2ClAn/PFu can be composites.

CONCLUSIONS

From thermal analysis, conductivity measurements, UV-VIS spectra, and SEM micrographs, it was found that PFu/P2ClAn and P2ClAn/PFu composites prepared in changing synthesis order had properties different from the PFu:P2ClAn (1:1) mechanical mixture and homopolymers. The thermal and conductivity properties of PFu and P2ClAn were modified by preparing the PFu/P2ClAn and P2ClAn/PFu composites. In particular, the conductivity value of PFu was increased 1000 times by preparing the P2ClAn/PFu composite. Moreover, the varying synthesis order of the polymers affected the structure, conductivity, and microstructural properties of the resulting polymers. The novel composites obtained could be utilized in the development of devices and applications in various areas.

References

- Sukeerthi, S.; Contractor, A. Q. *Ind J Chem* 1994, 33A, 565.
- Paul, E. W.; Ricco, A. J.; Wringhton, M. S. *J Phys Chem* 1985, 89, 1441.
- Mizumoto, M.; Namba, M.; Nishimura, S.; Miyadara, H.; Koseki, M.; Kobayashi, Y. *Synth Met* 1989, 8, C639.
- Monkman, A. P.; Adams, P. *Synth Met* 1991, 40, 87.
- Osaka, T.; Naoi, K.; Ogano, S. *J Electrochem Soc Electrochem Sci and Tech* 1988, 135, 5, 1071.
- Shilabin, A. G.; Entazami, A. A. *Eur Polym J* 2000, 36, 2005.
- Hernandez, V.; Ramirez, F. J.; Zotti, G.; Lopez Navarrete, J. T. *Chem Phys Lett* 1992, 191, 5, 419.
- Kang, E. T.; Neoh, K. G. *Eur Polym J* 1987, 23, 9, 719.
- Zotti, G.; Schiavon, G.; Comisso, N.; Berlin, A.; Pagani, G. *Synth Met* 1990, 36, 337.
- Kwon, A. H.; Conklin, J. A.; Makhinson, M.; Kaner, R. B. *Synth Met* 1997, 84, 95.
- Nishioka, Y.; Yoshino, K. *Jap J Appl Phys* 1990, 29, 4, L675.
- Li, X. G.; Huang, M. R.; Wang, L. X.; Zhu, M. F.; Manner, A.; Springer, J. *Synth Met* 2001, 123, 435.
- Gangopadhyay, R.; De, A.; Ghosh, G. *Synth Met* 2001, 21.
- Talu, M.; Kabasakaloglu, M.; Yildirim, F.; Sari, B. *Appl Surf Sci* 2001, 181, 51.
- Yang, C. Y.; Cao, Y.; Smith, P.; Heeger, A. J. *Synth Met* 1993, 53, 293.
- Saadeh, H.; Goodson, T.; Yu, L. *Macromol* 1997, 30, 4608.
- Xie, H. Q.; Liu, C. N.; Guo, J. S. *Polym Int* 1999, 48, 1099.
- Patil, R. C.; Ahmed, S. M.; Ogura, K. *Polym J* 2000, 32, 6, 466.
- Diaz, F. R.; Sanchez, C. D.; del Valle, M. A.; Tomes, J. L.; Tagle, L. H. *Synth Met* 2001, 118, 25.
- Sari, B.; Talu, M. *Synth Met* 1998, 221.
- Road, A. *Magnetic Susceptibility Balance, Instruction Manual; Christian Scientific Equipment: East Gateshead Industrial Estate, 1993; No. 6232, p. 8.*
- Talu, M.; Kabasakaloglu, M.; Oskoui, H. R. *J Polym Sci, Part A: Polym Chem* 1996, 34, 2981.
- Gupta, M. C.; Sindhimeshram, D. C. *Ind J Chem* 1994, 33A, 558.
- Demirboğa, B.; Önal, A. M. *Synth Met* 1999, 99, 237.
- Manohar, S. K.; MacDiarmid, A. G.; Cromcek, K. R.; Ginder, J. M.; Epstein, A. J. *Synth Met* 1989, 29, E349.
- Anond, J.; Palaniappan, S.; Sathyanarayana, D. N. *Eur Polym J* 2000, 36, 157.
- Mattoso, L. H. C.; Manohar, S. K.; MacDiarmid, A. G.; Epstein, A. J. *J Polym Sci, Part A: Polym Chem* 1995, 33, 1227.
- Gruger, A.; Novak, A.; Regis, A.; Colomban, P. *J Mol Struct* 1994, 328, 153.
- Patil, S. F.; Bedekar, A. G.; Patil, R. C. *Ind J Chem* 1994, 33A, 580.
- Shenglong, W.; Fosong, W.; Xiaohui, G. *Synth Met* 1986, 79, 11.
- Sharma, A. L.; Saxena, V.; Annopoorani, S.; Malhotra, B. D. *J Appl Polym Sci* 2001, 81, 1460.
- Wei, Y.; Tang, G. W.; Husch, K. F.; Sherr, E. M.; MacDiarmid, A. G.; Epstein, A. J. *Polymer* 1992, 33, 314.
- Yigit, S.; Hacıoğlu, J.; Akbulut, U.; Toppare, L. *Synth Met* 1996, 79, 11.
- Pandey, S. S.; Gerard, M.; Sherma, A. L.; Malhotra, B. D. *J Appl Polym Sci* 2000, 75, 149.
- Palaniappan, S.; Narayana, B. H. *J Polym Sci, Part A: Polym Chem* 1994, 32, 2431.
- Palaniappan, S. *Eur Polym J* 1997, 33, 10, 1735.
- Mattoso, S. E. M.; Faria, L. H. C.; Bulhoes, L. O. S.; MacDiarmid, A. G. *J Polym Sci, Part A: Polym Chem* 1994, 34, 2147.