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Conducting Semi-interpenetrating Polymer Network of Polypyrrole with Poly(esteramide urethane) Synthesized from a Sustainable Resource

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Semi-interpenetrating polymer networks of polypyrrole with poly(esteramide urethane) (CPEAU) synthesized from a sustainable resource, (coconut oil) is being reported for the first time. The semi-IPNs were prepared via chemical polymerization by immersing $FeCl_3$ *impregnated CPEAU films in a aqueous pyrrole solution for different time periods. CPEAU-Py semi-IPN films were found to be flexible, stiff, and having satisfactory conductivity when they were prepared by soaking in* $FeCl_3$ *up to 4 h. Soaking for higher periods led to the deformation of films. Soaking for less than 2 h in* $FeCl_3$ *resulted into poor polymerization of polypyrrole producing films of poor conductivity. Water uptake resulted in swelling of the films of pure CPEAU and was found to be maximum up to 10 wt%. Water uptake in the* $FeCl_3$ *impregnated CPEAU films decreased with the increase in the impregnation time and fell up to 5 wt% of* $FeCl_3$ *impregnated films. Conductivity of the semi-IPN films was found to be in the semi-conducting range* $2.9 \times 10^{-4}\ S\ cm^{-1} - 6.8 \times 10^{-6}\ S\ cm^{-1}$ *which happened to be higher than the conductivity values of the reported composites of poly(urethane)/polypyrrole. The semi-IPN formation was further investigated by FT-IR, thermal, and SEM analysis.*

Keywords interpenetrating polymer network, polypyrrole, poly(esteramide urethane), sustainable resource

Introduction

For the past few decades, various strategies have been adopted to improve the processing and mechanical properties of organic conducting polymers such as polyaniline, polypyrrole, polythiophene, etc. by the formulation of blends, composites, as well as interpenetrating polymer networks of these polymers with commercial polymers (1–3). To develop conducting polymer-based materials for commercial applications such as display devices, sensors, electrodes for batteries, etc., efforts are being made for the

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preparation of polypyrrole-polymer composite having good processibility, conductivity, and improved mechanical characteristics (4–6).

Conducting composites of polypyrrole with styrene-co-butyl acrylate (7), epoxy (8), polyvinylchloride (9), polycarbonate (10) and polyurethane (11) have been investigated and their conductivities were found in the range 8×10^{-4} S cm^{-1}, 6×10^{-5}, 8.2×10^{-1} S cm^{-1} and 2.36×10^{-4} S cm^{-1} to 7.71×10^{-5} S cm^{-1}, respectively. Conductive polyurethane foams, conductive films of poly(vinylpyridine) and conductive flexible matrices of cross-linked styrene-co-acrylate copolymers have been synthesized using polypyrrole vapors (12, 13). The polypyrrole composites were mostly synthesized by exposing $FeCl_3$ impregnated matrix films to aqueous polypyrrole solution (14, 15). These systems exhibited conductivities in the range of 0.12–0.3 S cm^{-1}. As polypyrrole has a highly cross linked structure (16), composites prepared by the above mentioned method are generally referred to as IPNs or semi-IPNs depending upon the extent of cross-linking of one or both components.

Interpenetrating polymer network (IPN) is an assembly of interpenetrating networks of two polymers (having or not having any mutual chemical interaction) where atleast one is synthesized in the presence of the other. In some cases, one of the component polymers undergoes partial cross-linking into the matrix of the other producing a semi-IPN (27). IPNs/semi-IPNs represent an interesting technique of blending of two polymers where the constituents are physically entangled and their unique combination provides a wide range of desired properties. They can be prepared by a "two step simultaneous technique" where the polymer is *in situ* polymerized and simultaneously crosslinked within the network of other polymer. An alternative technique involves sequential addition of selective crosslinker to a homogeneous mixture of two polymers in solution or in melt form. However, the physical and chemical nature of the individual constituents and their proportion control the ultimate performance of the IPNs. As conducting polymers are generally insoluble and infusible in nature, they do not form homogeneous solution owing to a stiffness of backbone. Hence, IPNs based on conducting polymers are generally referred to as semi-IPNs as the extent and nature of crosslinking is not equivocally established. The attraction of combining the electrical properties of conducting polymers with the mechanical properties of commercial polymers has guided scientists to find different methods of synthesis for conducting polymer based IPNs or semi-IPNs. These semi-IPNs can be electrically conductive only after suitable doping where the conductivity depends upon the structure of the doped IPN/semi-IPN and nature of dopants. The percolation limit of the semi-IPNs is found to be generally lower than that for statistical blends (17).

Efforts have been directed to substitute petroleum as resource of polymers, as the latter is expected to reach the point of exhaustion by the end of 21st century (18, 19). Vegetable oils, a sustainable resource, have a number of interesting properties that can be utilized in making polymers (such as alkyds, polyurethanes, epoxy resins, polyesteramides) of commercial significance (20–22). Interpenetrating polymer networks of desirable properties of urethane/acrylic and urethane/vinyl monomers systems using sequential, as well as simultaneous polymerization, are well known and have been reviewed in detail by many authors (23–26).

A literature survey reveals that no work has been reported on the sequential or simultaneous polymerization of conducting polymers with vegetable oil based polymers. Polypyrrole is a hard and brittle polymer and possesses poor mechanical properties, while poly(esteramide urethane) derived from coconut oil is a flexible thermoplastic polymer. The combination of the two polymers is expected to be synergistic in nature yielding a blend with improved thermal and mechanical and also good conducting properties. We have chosen poly(esteramide urethane) (CPEAU) because it gives freestanding films while unmodified polyesteramide(CPEA) fails to give such films.

The present work reports on the synthesis of a semi-interpenetrating polymer network of polypyrrole with poly(esteramide urethane) (CPEAU), synthesized from the sustainable resource, coconut oil. Polypyrrole was polymerized within $FeCl_3$ impregnated CPEAU films by immersing them in an aqueous solution of pyrrole monomer. Effect of ferric chloride on the extent of polymerization of polypyrrole into the CPEAU films and on the formation of semi-IPN was further investigated by FT-IR, DSC, TGA, SEM and conductivity studies.

Experimental

Pyrrole and toluylene diisocyanate were procured from Merck, Germany. Pyrrole, (Merck, Germany) was distilled twice under vacuum and stored in a refrigerator prior to use. Coconut oil was procured from Shankar Dyes and Chemicals, Delhi (India) and was dewaxed and purified prior to use. Phthalic acid, xylene, diethanolamine (all from Merck, India) and ferric chloride (s.d. Fine Chem., India) were of analytical grade and were used as such.

Synthesis

N,*N*,bis(2-hydroxy ethyl)coconut oil fatty amide(HECA), coconut oil polyesteramide (CPEA) and coconut poly(esteramide urethane) (CPEAU) were synthesized after a reported method (22). A brief account of the synthesis of each of them is given below.

Preparation of N,N,bis(2-hydroxy ethyl) Coconut Oil Fatty Amide (HECA)

Diethanolamine (0.32 mol), and sodium methoxide (0.007 mol) were taken in a three-neck round bottom flask fitted with magnetic stirrer, dropping funnel, condensor, thermometer and nitrogen inlet tube. The reaction mixture was heated to 120 ± 5°C. Coconut oil (0.1 mol) was added dropwise into the reaction mixture over a period of 60 min. The progress of the reaction was monitored by TLC (22). The reactants were further heated for 2 h at 120°C ± 5°C to ensure the complete conversion of oil into HECA. After cooling, the product was dissolved in diethylether, washed several times with 15% aqueous NaCl solution and dried over anhydrous sodium sulphate. The ethereal solution was filtered and evaporated in a rotary vacuum evaporator to obtain HECA.

Coconut Polyesteramide (CPEA)

HECA (0.08 mol), phthalic acid (0.08 mol) and 50 ml xylene were placed in a three-neck round bottom flask fitted with Dean Stark trap, nitrogen inlet tube, thermometer, and mechanical stirrer. The reaction mixture was heated at 180°C ± 5°C and refluxed until a theoretical amount of water was collected in the Dean Stark trap. The progress of the reaction was monitored by TLC and acid value determination. The reaction mixture was further refluxed for 5–6 h to complete the reaction. The product was taken from the reaction flask and xylene was removed under reduced pressure using a rotary vacuum evaporator to obtain the CPEA.

Coconut Poly(esteramide urethane) (CPEAU)

CPEA (10 g) was taken in a three-neck round bottom flask fitted with magnetic stirrer, dropping funnel, condensor, thermometer, and nitrogen inlet tube. Toluylene diisocyanate [TDI] (0.5 g) was added dropwise into the reaction mixture at 100°C ± 5°C for 30 min. The reaction was monitored by TLC, and acid value determination (22). Xylene was removed from the reaction mixture in a rotary vacuum evaporator.

Preparation of Films of CPEAU

Films of CPEAU were obtained from a 20% solution in xylene.The solution was poured on a transparency sheet and drying of the films was carried out for 72 h. The films obtained were further dried in a vacuum oven at 60°C for 48 h to ensure complete removal of the solvent.

In Situ Polymerization of Pyrrole in CPEAU Films

The polymerization of pyrrole within the CPEAU films was carried out by a method reported by several authors (11, 14, 15). Films of CPEAU (2 cm × 1 cm × 0.1 cm) were initially weighed and first immersed in a 0.4 M aqueous ferric chloride solution at room temperature (30°C) in a petri dish for two different intervals of time: 2 and 4 h, respectively with a view to obtain two different loadings of ferric chloride in the films. In a preliminary experiment, we have found that ferric chloride impregnation for less than 2 h caused poor polymerization of the polypyrrole while impregnation for more than 4 h produced hard and brittle films. Impregnation was therefore done for 2 and 4 h. The final weight gain of the films was recorded and the films were then wiped, dried with tissue and immersed in an aqueous polypyrrole solution (0.2 M) for different time intervals as given in Table 1. The weight gain was monitored at regular intervals of time (0.5, 1, 1.5 and 2 h). The films were then withdrawn, and washed several times with distilled water to ensure complete removal of unreacted ferric chloride, weighed again to check the weight loss and further dried under vacuum at 60°C for 48 h. The IPNs containing different wt% loading of

Table 1
Characteristics of CPEAU/Py semi-IPNs, $FeCl_3$ impregnation time, percent loading and their conductivities

IPN (CPEAU/Py)	Exposure time in Ferric chloride (Hrs)	Exposure time in pyrrole solution (Hrs)	Percent loading of polypyrrole in PEAU (wt%)	Conductivity (S cm^{-1})
CPEAU/Py-I	2	0.5	3.5	6.8×10^{-6}
CPEAU/Py-II	2	1	4.0	5.3×10^{-5}
CPEAU/Py-III	2	1.5	5.0	5.1×10^{-5}
CPEAU/Py-IV	2	2	5.5	4.7×10^{-5}
CPEAU/Py-V	4	0.5	4.5	4.7×10^{-5}
CPEAU/Py-VI	4	1	7.5	3.5×10^{-4}
CPEAU/Py-VII	4	1.5	9.0	3.3×10^{-4}
CPEAU/Py-VIII	4	2	9.5	2.9×10^{-4}

polypyrrole were obtained as given in Table 1. The CPEAU/Py films have been coded as I, II, III, IV, V, VI, VII, and VIII according to a soaking period in $FeCl_3$: time of immersion in pyrrole solution (in hours) as CPEAU/Py-I (2:0.50), CPEAU/Py-II (2:1), CPEAU/Py-III (2:1.5),CPEAU/Py-IV(2:2), CPEAU/Py-V (4:.50), CPEAU/Py-VI (4:1), CPEAU/Py-VII (4:1.5) and CPEAU/Py-VIII (4:2) as shown in Table 1.

Water Absorption

Water absorption studies of the films were carried out as pyrrole was polymerized within CPEAU films from its aqueous solution. In a separate experiment, CPEAU films were soaked in distilled water for different periods and water uptake was monitored at regular intervals of time until a constant weight gain was obtained.

Characterization

The physico-chemical characterizations of CPEAU viz. acid value, hydroxyl value and refractive index were carried out by standard methods (22). The values of these properties are given in Table 2. FT-IR spectra of the films were taken on a spectrophotometer model BIO-RAD WIN-IR. Thermal behavior of the films was studied on differential scanning calorimeter model DSC-10 of TA instruments, USA, and on a thermogravimetric analyzer model TGA51 of T.A Instruments USA. Scanning electron micrographs of the films of various compositions were taken on JEOL (JSM840) scanning electron microscope under the gold film. Conductivity was measured by a standard four-probe method at 30°C.

Results and Discussion

Physico-Chemical Characteristics of CPEAU

The physico-chemical properties of the films are given in Table 2. On incorporation of TDI (5 wt%) in CPEA, the acid value and hydroxyl value decreases from the corresponding values in HECA and CPEA. This indicates the increase in the molar mass on the incorporation of TDI in CPEAU which is corroborated by the higher values of specific gravity of CPEAU as compared to HECA and CPEA.The refractive index of CPEAU is also found to be higher than CPEA.

Table 2

Characterization of coconut oil, HECA, CPEA and CPEAU

Characteristics	Coconut oil	HECA	CPEA	CPEAU
Acid value (mg KOH)	8.0	—	7.2	6
Hydroxyl value (%)	5.7	—	5.4	3
Refractive index (at 30°C)	1.468	1.486	1.389	1.455
Specific gravity (at 30°C)	0.5596	—	0.6355	0.6615
Linoleic acid (%)	2%	—	—	—
Saturated fats (%)	92%	—	—	—
Oleic acid (%)	6%	—	—	—

Film Characteristics of CPEAU

CPEAU films were found to be flexible and poor in stiffness, however on impregnation with $FeCl_3$ the stiffness of the films increased, the mechanism of which is explained in a latter section. The stiffness of the film was found to increase with the impregnation time and stiffness of the films impregnated with $FeCl_3$ for 4 h was higher than those impregnated for 2 h. It was noticed that immersion in $FeCl_3$ below 2 h did not show significant polymerization of pyrrole while prolonged immersion in $FeCl_3$ for over 4 h resulted in the deformation of the films.

CPEAU films were pale brown in color and any change in texture or color of the films was not visually observed on soaking in distilled water, $FeCl_3$ impregnated CPEAU films also showed no change in color or texture even on prolonged immersion in water during the investigation of swelling behavior. This can be attributed to the significant electrostatic interaction between $FeCl_3$ with CPEAU. However, it was observed that on polymerization of polypyrrole in the films, the color turned dark brown.

Water Absorption Studies

Water absorption and $FeCl_3$ absorption studies were investigated since polypyrrole was synthesized within CPEAU films. Percent water absorption was studied for neat CPEAU and $FeCl_3$ impregnated CPEAU films by immersing them in distilled water for different intervals of time. It was noticed that water uptake of CPEAU films was between 10–15 wt% after 72 h, (Figure 1) while that of $FeCl_3$ impregnated films was hardly 4–5 wt% after 72 h (Figure 2). This can be explained as follows:

Results of swelling of ferric chloride impregnated polymer films into water showed relatively low uptake of water by the films. $FeCl_3$ exists as dimer or in higher aggregated state in the pores of CPEAU matrix when its films are impregnated with aqueous $FeCl_3$. The electrolyte concentration inside the films will therefore be greater, occupying a larger space of micropores that will cause reduction in the uptake of water molecules and consequently, the lower swelling of the polymer film.

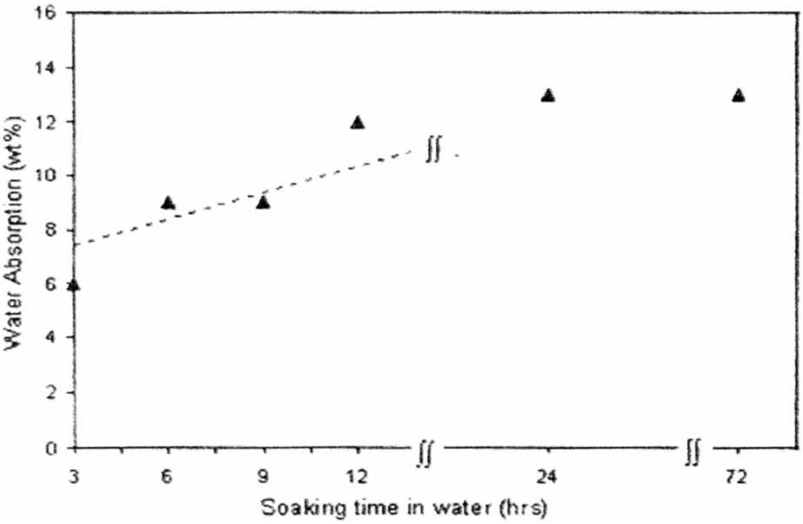

Figure 1. Water absorption studies of CPEAU films.

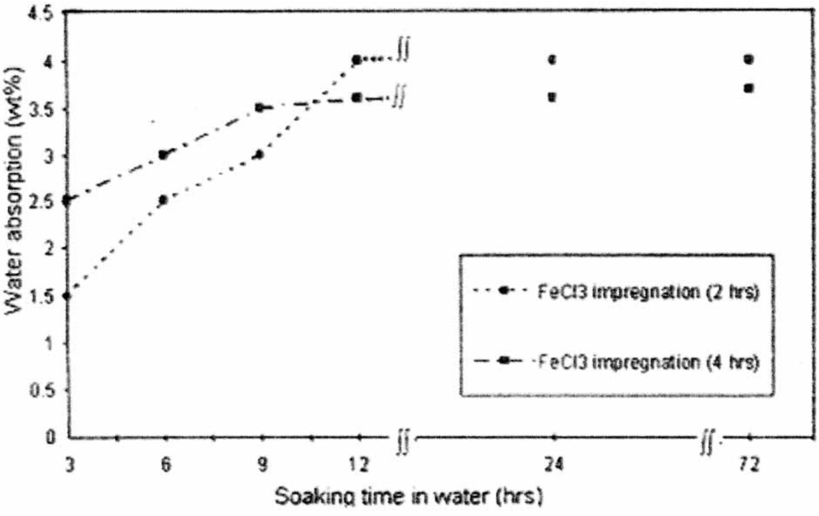

Figure 2. Water absorption studies of 2 and 4 h $FeCl_3$ impregnated CPEAU films.

The rate of incorporation of polypyrrole in the 2 and 4 h $FeCl_3$ impregnated films was also investigated. It was found that in both cases the rate of incorporation gradually increased and became nearly constant after 2 h. About 80% polymerization took place in the first 1 h, (Table 2) and became constant after 2 h, giving 5 wt% and 10 wt% loading in the case of 2 h and 4 h impregnated films, respectively. The relatively higher amount of polypyrrole formation in 4 h $FeCl_3$ impregnated films could be attributed to the excessive polypyrrole formation in CPEAU matrix owing to the presence of a greater amount of $FeCl_3$ oxidant. Interestingly, any formation of the polypyrrole outside the film was not observed in the same solution showing that ferric ions did not diffuse out of the film during its exposure in aqueous pyrrole solution and hence, were held onto their position in CPEAU matrix.

The CPEAU films prior to impregnation and *in situ* polymerization were found to be soluble in acetone chloroform, benzene, tetrahydrofuran and all polar solvents. However, CPEAU/Py films were found to be insoluble in chloroform, acetone, and benzene while they were found to be sparingly soluble in THF and other polar solvents. The insolubility indicates the incorporation of polypyrrole chains within the CPEAU matrix, which influences its overall solubility.

We have referred to this system as semi-IPN rather than full IPN as some authors have established that *in situ* polymerization of aniline or pyrrole results in partial cross-linking of the polymer matrix (27). At the same time, it is also well known that during chemical polymerization, the conducting polymer is synthesized in partially crosslinked/branched form where the extent and nature of crosslinking is not properly controlled. This type of network formation is also termed as semi-IPN (27). The morphology of the blend has been discussed in the latter section.

FT-IR Spectra

The FT-IR spectra of the films of CPEAU and polypyrrole loaded films were taken. The spectra of pristine CPEAU, Figure 3(a), shows broad and deep O-H peak centered at

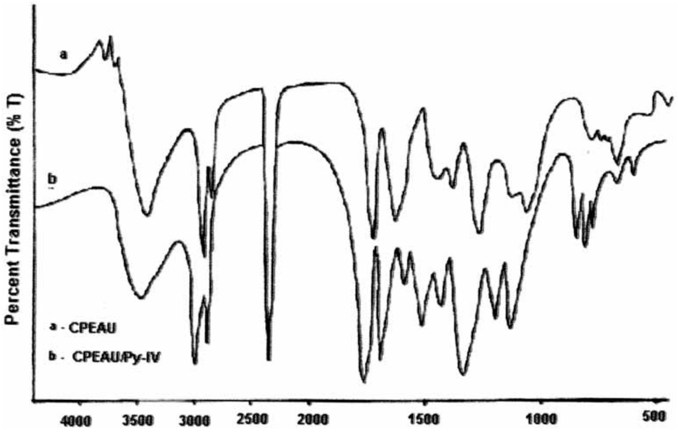

Figure 3. FT-IR spectra of (a) CPEAU (b) CPEAU/Py-IV.

3425 cm^{-1}, the N-H vibration peak appears to be submerged in the foregoing peak. The CH$_2$ asymmetric, CH$_2$ symmetric, and carbonyl ester peaks are found, respectively at 2925 cm^{-1} and 2855.3 cm^{-1} and 1727 cm^{-1}. We observe peaks at 1631 cm^{-1} and 1265 cm^{-1} for carbonyl and C–O–C of the urethane group. The CN peak appears at 1069.5 cm^{-1}. The neat and well-formed peaks in the whole spectral range can be attributed to a very uniform and well formed chain structure of CPEAU. On formation of polypyrrole in the CPEAU matrix, the blend CPEAU/Py-IV, (Figure 3(b) shows the emergence of new peaks due to a pyrrole group at 530 cm^{-1}, 719.9 cm^{-1}, 745.9 cm^{-1} and 775.2 cm^{-1}, respectively. We notice a change of almost 5 cm^{-1} in the urethane carbonyl peak at 1631 cm^{-1} and, of about 7–8 cm^{-1} in the C–O–C peak at 1265 cm^{-1} towards the higher frequency side. The increase in the stiffening of the C=O and C–O–C bonds of the urethane group may be attributed to the presence of ferric ions in the space between the two oxygen atoms of the above groups and the resulting electrostatic attraction between them would produce strain in these bonds causing increase in their frequency of absorption.

It appears that on these sites ferric ion initiates polymerization of pyrrole in the CPEAU matrix yielding well formed, almost linear, chains which is supported by the presence of very well formed and neat peaks in the entire spectral range. The pattern of linear poly(esteramide urethane) (CPEAU) and polypyrrole chains as inferred from IR spectra and also SEM micrographs help in the formation of semi-IPN of the above blend. The decrease in the stretching frequency of OH peaks, as well as the broadening of the peak in the blends of different compositions, indicates hydrogen bonding between the NH group of polypyrrole and the OH of CPEAU.

TGA

The TGA thermogram of CPEAU, (Figure 4) shows a sluggish decomposition with 10 wt% loss up to 235°C and 50 wt% loss at 335°C, while almost 80 wt% loss occurs at 385°C. A similar, but slightly steep, decomposition curve is observed in the case of semi-IPN of composition CPEAU/Py-I, wherein 10 wt% loss takes place at 260°C and 50 wt% loss at 350°C, while 80 wt% loss is found to occur at 410°C. Similar weight loss behavior is observed in the case of semi-IPN of compositions CPEAU/Py-IV,

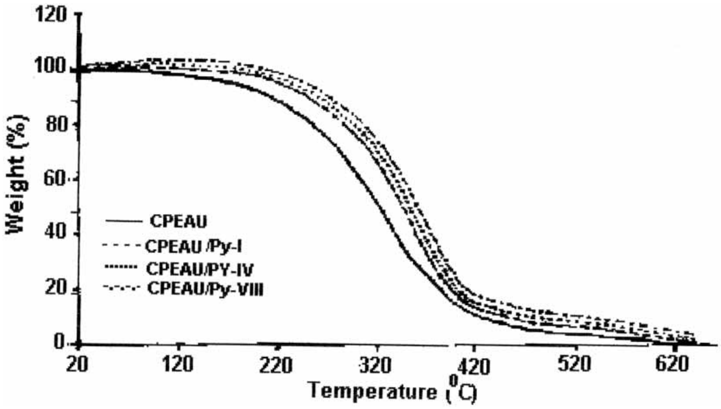

Figure 4. TGA thermogram of CPEAU and CPEAU/Py semi-IPNs.

CPEAU/Py-V, and CPEAU/Py-VIII. It is observed that the thermal stability increases with the increased amount of polypyrrole in the blends.

DSC

The DSC thermogram of pure CPEAU, Figure 5, shows endothermic event between 120°C–170°C and a decomposition event starting at about 220°C. The endothermic peak can be correlated to the melting of the polymer. We have visually observed that CPEAU melts at this temperature. In the semi-IPN CPEAU/Py-III, an endothermic peak spanning over 125°C–175°C and an exothermic peak extending from 220°C onwards is observed. The DSC trace of IPN CPEAU/Py-VI shows the starting of the endothermic peak around 145°C which spreads up to 250°C and merges into the ensuing decomposition event. The shifting of the endothermic peak of melting to higher temperatures indicates stiffening of the matrix with an increased amount of polypyrrole

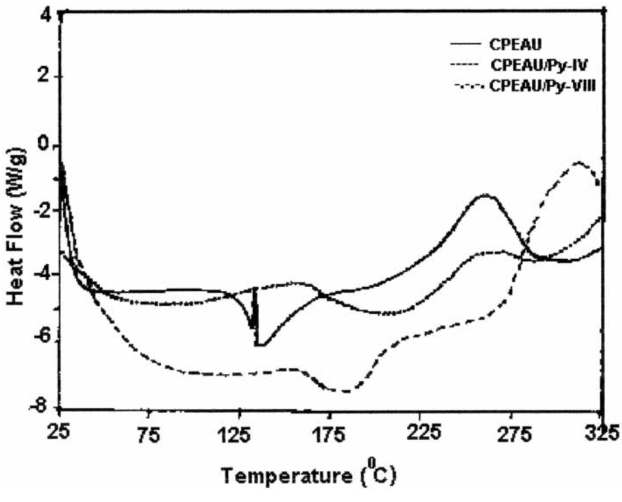

Figure 5. DSC thermogram of CPEAU and CPEAU-Py semi-IPNs.

in the semi-IPNs. The same was observed visually and is also corroborated by FT-IR spectra.

It can further be inferred that the exposure of CPEAU films in $FeCl_3$ and pyrrole markedly influences the molecular organization of the semi-IPN. Higher loading of $FeCl_3$ and pyrrole causes more stiffening in the films that further pushes the endothermic event upward causing it to merge with the subsequent decomposition events.

Morphology

Comparing the micrographs of the blends CPEAU/Py-I, CPEAU/Py-IV, CPEAU/Py-VIII (Figure 6(a, b, c)), respectively, it appears that with an increase in polymerization time, the polypyrrole phase grows progressively in the matrix. On maximum polymerization, pyrrole appears as fibrillar chains joined with each other laterally. The microstructure, (Figure 6(c)) shows that polypyrrole, is highly crosslinked. It can be observed that only one phase appears to be highly crosslinked, while the other phase exhibits a discrete linear pattern. The CPEAU/Py blend is therefore a semi-IPN in structure (27). The networked structure of polypyrrole chains would impart flexibility, stiffness, and conductivity to the films. The conductivities of semi-IPNs of compositions CPEAU/Py-I, CPEAU/Py-IV, and CPEAU/Py-VIII was found to be 6.8×10^{-6}, 4.7×10^{-5} and 2.9×10^{-4}, respectively. The increase in conductivity with the time of polymerization is in accordance with the microstructure development and with the gradual increase in network formation in these compositions. It has been pointed out by Mandal and co-workers (17) that the conductivity of semi-IPNs is generally higher than that for normal blends as in the latter case, the distribution of the conducting polymer is highly random and is in the form of dispersed particles, while in the case of semi-IPN, the growth of the conducting polymer is gradual and ordered resulting in an interconnected network formation.

Conductivity

Table 1 shows the conductivities, as determined by a standard four-probe method at 30°C of CPEAU/Py semi-IPNs of different compositions carrying different loading of Py. The conductivity was found to be dependant on both $FeCl_3$ and polypyrrole loading. The conductivity in the case of semi-IPNs, obtained by 4 h impregnation in a $FeCl_3$ solution resulting into higher loading of polypyrrole, is found to be almost one order higher than the conductivity of semi-IPNs obtained by impregnation for 2 h in $FeCl_3$. This resulted in lower loading of Py. Interestingly, it is found that in both cases (with 2 and 4 h impregnation in $FeCl_3$), the conductance increases with the increased loading of polypyrrole and is then found to decrease on further loading (samples CPEAU/Py-I to CPEAU/Py-III and CPEAU/Py-VI to CPEAU/Py-VIII), Table 1. This can be attributed to some structural deformation of the films of the semi-IPNs on prolonged immersion in a pyrrole solution which ultimately distorts their ordered morphology, as well as their network structure and hence, lowers the conductivity. It is also visually noticed that the $FeCl_3$ impregnated CPEAU films, immersed for 2 h in pyrrole solution, showed the slight distortion, which can be correlated to the decrease in the conductivity of the semi-IPN films. The higher value of conductivity in the case of CPEAU/Py-VI having 7.5 wt% of Py may be due to the optimum network formation. Among all the films obtained on exposure of 2 and 4 h $FeCl_3$ impregnated CPEAU films in a pyrrole solution for different times, the ones obtained on 1 h exposure in each case showed the maximum conductance of

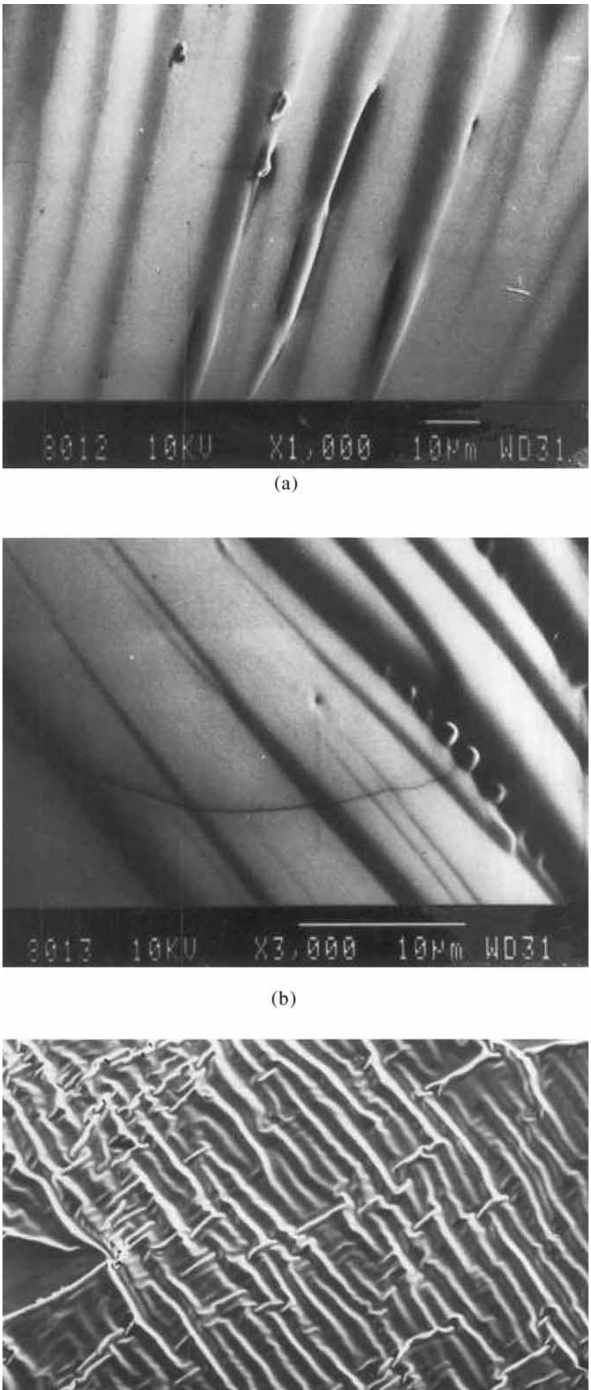

Figure 6. SEM micrographs of (a) CPEAU/Py-I, (b) CPEAU/Py-IV and, (c) CPEAU/Py-VI.

5.3×10^{-5} and 3.5×10^{-4} S cm^{-1}, respectively, though the amount of polypyrrole in the former case was 4 wt% and in the latter case was 7.5 wt%. On closely examining the values of conductivities as given in Table 1 and SEM micrographs of Figure 6, it can be inferred that conductivity not only depends upon the absolute amount of Py loading but also on the relative proportion of $FeCl_3$ and Py, the distribution of polypyrrole chains in the matrix and network formation in the semi-IPN. It is noticed that conductivity approaches the higher limit of the conductivity range on the optimum balance of the above factors.

The conductivity values obtained in this study are higher than those reported for Py/PU composites (11) (between 10^{-4}-10^{-9} S cm^{-1}) and comparable to the values reported by Mandal and coworkers for Py/PVAc composites (17) and can be attributed to the morphology of the films.

Conclusions

The synthesis of semi-IPNs of polypyrrole with coconut oil derived poly(esteramide urethane) CPEAU by the immersion method exhibits an easy way of processing conducting polymers, giving films of fair mechanical strength, flexibility, and good conductivity. It also provides an alternative route to substitute petroleum based polymers by those obtained from a sustainable resource to develop conducting polymer-based semi-IPNs which may find specific applications in improving solvent resistance, mechanical properties of different polymers, and also in control release of drugs, as well as other reactive materials.

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