We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

7,500
Open access books available

196,000
International authors and editors

215M
Downloads

Our authors are among the

154
Countries delivered to

TOP 1%
most cited scientists

14%
Contributors from top 500 universities

CLARIVATE ANALYTICS
BOOK CITATION INDEX
INDEXED

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Chapter

Conducting Low-Density Polyethylene/Polyaniline Blends for Antistatic Applications

Ayse Nur Ozkan, Kamil Sirin and Fatih Dogan

Abstract

Intrinsically conducting polymers (ICPs) are utilized in numerous industrial sectors. ICPs' electrostatic charge dissipative (ESD) properties are one of their most crucial application characteristics, particularly in electronics. Therefore, in this study, the mechanical, morphological, thermal, and ESD properties of low-density poly(ethylene) (LDPE) and polyaniline (PANI) blends were discussed. Blends were prepared by loading 0.5, 1.0, and 3 wt% of PANI into the LDPE matrix by solution blending method. Then, FT-IR, DSC, TGA, DMA, SEM, and X-RD techniques were used to analyze the interaction between PANI and LDPE. The thermal durability of polyethylene did not change with the addition of PANI. The addition of PANI to the LDPE matrix resulted in a melting temperature drop of about 1°C. However, the degree of LDPE crystallinity dramatically reduced as the amount of PANI in the blends increased. Additionally, the conductivity of the PANI/LDPE blends was determined to be in the range of 10^{-6}–10^{-9} S cm^{-1}. The antistatic decay curves showed that all blends can be used as ESD material at 3 kV corona voltage. Moreover, it has been seen that the LDPE blend, which is doped with 3% PANI by weight, can be used as negative and positive polarizable ESD material between −3 and 6 kV corona voltages.

Keywords: conducting polymer blends, LDPE, PANI, crystallinity, antistatic applications

1. Introduction

Polymers are materials that are widely used in our daily lives. It has many uses such as clothes, household items, packaging, and many plastic-based materials. Polymers have a wide range of applications due to their molecular structure. Due to their low density, they are relatively light, workable, and flexible. In addition, their use has increased gradually due to their cheapness. While polyethylene (PE) ranks first in plastic production and consumption in the world at 32%, polypropylene (PP) ranks second at 20%, and poly (vinyl chloride) (PVC) ranks second at 17% [1]. In recent years, the increase in the usage areas of polymers has accelerated the studies in polymer science and technology, and scientists have started to work on synthesizing new polymers and improving their properties. Polymers were known as electrically

insulating materials with conductivity values between 10^{-7} and 10^{-14} S cm^{-1}. It began in 1977 after MacDiarmid and Heeger's conversion of polyacetylene from an insulating state to a conducting state by reduction and oxidation reactions [2]. After the invention of electrically conductive polyacetylene, various conductive polymers have been developed. Among the conductive polymers, PANI is a preferred material for many applications because of its monomer being inexpensive, easy to synthesize, stable, and high conductivity due to doping [3]. PANI is used in a wide variety of next-generation technologies such as solar cells, rechargeable batteries, sensors and capacitors, electromagnetic radiation shielding, gas separation membranes, electrochromic devices, and antistatic coatings [4]. Particularly, antistatic properties of conductive polymers are a very important issue in the electronic industry such as computer internal parts, data storage devices, and chip carriers. Also, the most important problem in the electronic industry is electrostatic discharge. In our daily life, sparks, fires, and explosions can occur due to electrostatic accumulation on many materials. These undesirable consequences can cause injury to people and even death, as well as malfunction of devices. Also, static electricity causes the accumulation of dust, which decreases the attractiveness of materials [5]. The importance of this problem is understood and to solve the problem, efforts have been accelerated. Literature suggests ESD protection by adding antistatic agents such as conductive polymers, carbon nanotube, carbon black, and graphite to make conventional polymers partially electroactive. The conductivity value of the material to be used as an antistatic agent should be between 10^{-6} and 10^{-11} S.cm^{-1} [6]. Blending PANI with common polymers such as PP, LDPE, ABS improves the processibility of PANI and creates novel materials with ESD, electromagnetic shielding, and corrosion prevention properties. Nand et al. prepared blends of linear low-density polyethylene (LLDPE) and nanorod-polyaniline (NR-PANI) *via* extrusion by 5, 10, 15, and 20 wt% loading of NR-PANI. A maximum conductivity value of $1.93.10^{-14}$ S cm^{-1} was obtained without doping any acids [7]. Bhandari et al. prepared conducting copolymers of aniline (AN) and 1-amino-2-naphthol-4-sulfonic acid (ANSA) blended with LDPE. Loading 0.5 and 1.0 wt % of the conducting copolymer into the LDPE matrix was performed in a twin-screw extruder. The conductivity of the blends was found to be in the range of 10^{-6}–10^{-11} S.cm^{-1}. The static decay time of the blends was found to be 0.1–1.9 sec from 5000 to 500 V [6]. It was determined that the lower loading of NASA can be effectively used for the dissipation of electrostatic charge [8]. This study aims to provide moderate conductivity to LDPE with low loading of PANI and investigate the blends' electrostatic charge dissipative performance. Blends were prepared by loading 0.5, 1.0, and 3 wt % of PANI into the LDPE matrix in solution medium. The mechanical, morphological, and thermal properties of resulting binary blends were also examined. The conductivity of blends is measured at three different temperatures. Finally, the antistatic decay time of blends was performed at Corona voltages between 9 kV and 9 kV.

2. Experimental

2.1 Reagents

All chemicals were of analytical grade. N-methyl-2-pyrrolidinone (NMP, 99%) and toluene ($C_6H_5CH_3$, 99.5%, from Aldrich Chemicals Co.) were used as received. Aniline monomer premium grade from Merck and LDPE in powder form obtained from *Petkim Petrokimya Holding* Company (Türkiye) was used as received.

2.2 Preparation of resulting blends

The blends were prepared by the solution blending method. First, solvent selections were made in which polyaniline and LDPE can be dissolved. NMP was chosen as the solvent to dissolve PANI and toluene was chosen for LDPE. About 3 g of LDPE was dissolved in 100 ml of toluene by heating at 80°C on a magnetic stirrer. About 15 mg of PANI was put into 8 ml of NMP and kept in an ultrasonic bath for 20 minutes and dissolved. Then, PANI solution (dark green color) was added to the LDPE solution (transparent color) as seen in **Figure 1**. After 15 minutes, the mixture was poured into a glass petri dish and kept for 1 hour at room temperature and then in a vacuum oven at 70°C overnight.

Subsequently, the amount of polyaniline was increased to 30 mg and 90 mg, and PANI/LDPE blends were prepared in different proportions. Blends of low-density polyethylene/polyaniline (LDPE/PANI), containing 0.5, 1, and 3 wt % polyaniline have been obtained (**Figure 2**). The abbreviated nomenclature $LP_{0.5}$, LP_1, and LP_3 correspond to LDPE containing 0.5 wt%, 1 wt%, and 3 wt% PANI for all blends with LDPE and PANI, respectively.

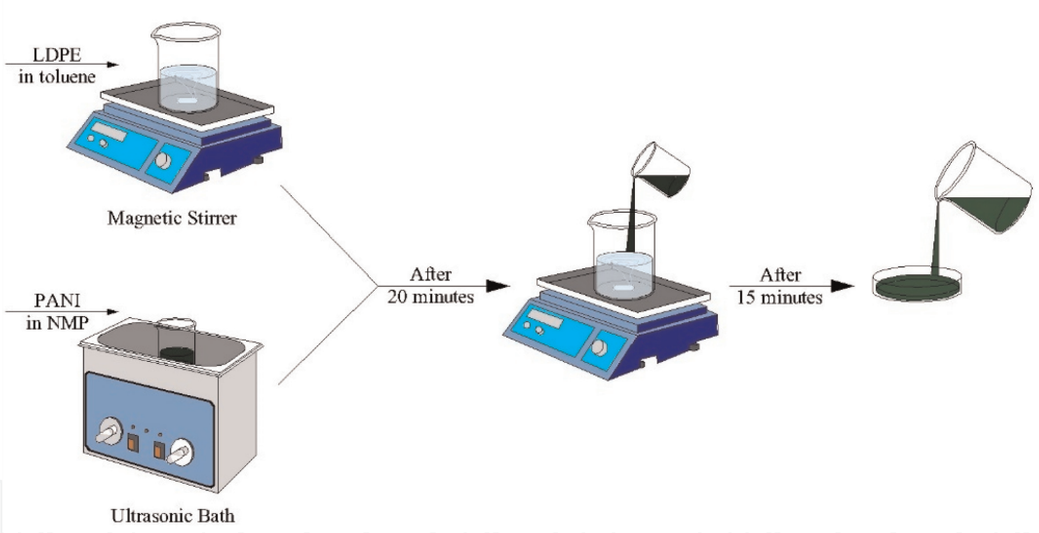

Figure 1.
Schematic illustration of the preparation of the LDPE/PANI blends.

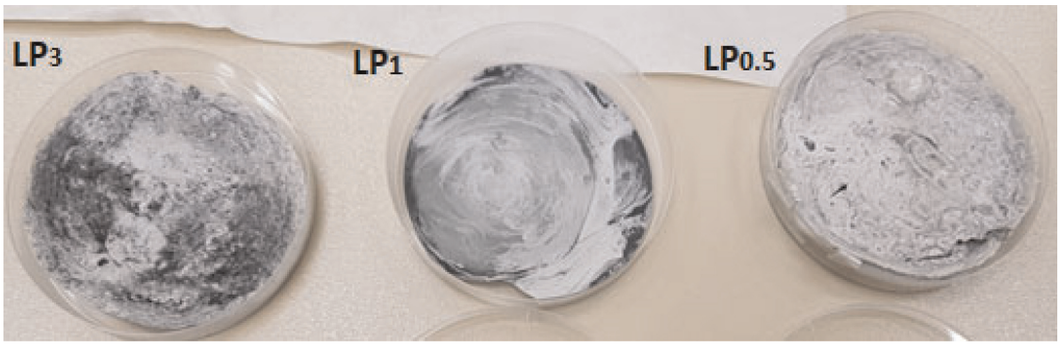

Figure 2.
Images of LP_3, LP_1, and $LP_{0,5}$.

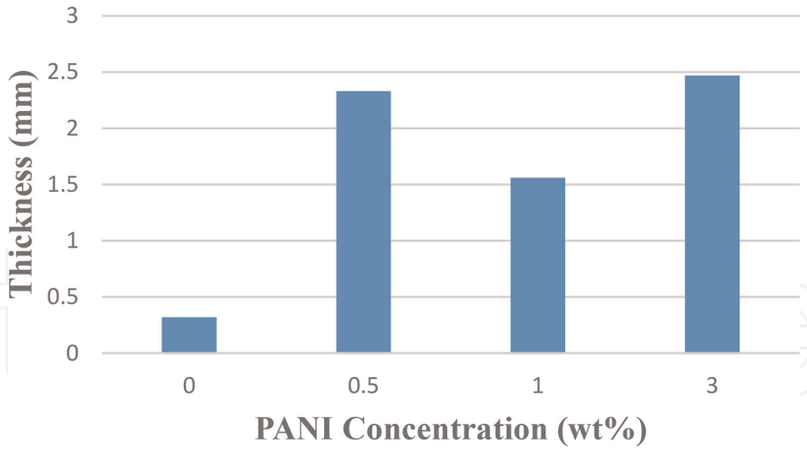

Figure 3.
Thickness of LDPE, $LP_{0.5}$, LP_1, and LP_3.

All blends were prepared in 10 cm glass petri dishes. The thickness of the samples increased with the addition of PANI. **Figure 3** shows the graph related to the blends' thickness.

3. Results and discussion

3.1 FTIR analysis of resulting blends

FTIR spectra of the resulting blends were recorded using a Perkin Elmer-Spectrum BX FTIR spectrophotometer between 4000 and 400 cm^{-1}. The FTIR spectra of LDPE blends prepared with various amounts of PANI are shown in **Figure 4**. The bands seen at 2913, 2846, 1466, 1369, and 715 cm^{-1} in the spectrum given were attributed to -CH_2 asymmetric vibration, -CH_2 symmetrical vibration, bending deformation vibration, -CH_3 symmetrical strain vibration, and oscillating strain vibration, respectively. The band seen at 1369 cm^{-1} showed that the polyolefin-based material was LDPE. The 3445 cm^{-1} broad N-H peak specific for PANI is also seen in the spectrum. As stated in the literature [7], the presence of specific peaks in both materials and the absence of other new formation peaks are proof that resulting blends are physically blended.

3.2 TG/DTG analysis of resulting blends

Thermogravimetric analyses were carried out at a heating rate of 10°C.min^{-1}, starting from room temperature up to 600°C. The temperature values corresponding to the highest degradation rate of the blends, and % mass losses were measured. **Figure 5** shows the TG/DTG analysis of pure LDPE and its blends. Accordingly, it is seen that pure LDPE decomposes in one step, but blends decompose in two steps. The degradation curve of the blends seen in the first step is thought to be due to solvent evaporation. LDPE also causes the second degradation. It was observed that the temperature values corresponding to the highest degradation rate of pure LDPE and $LP_{0.5}$, LP_1, and LP_3 were around 478°C, which are given in **Table 1**. There is not a clear change in the thermal stability of PE. In other words, there is no difference in the temperature at which PE chains begin to deteriorate. When the DTG values

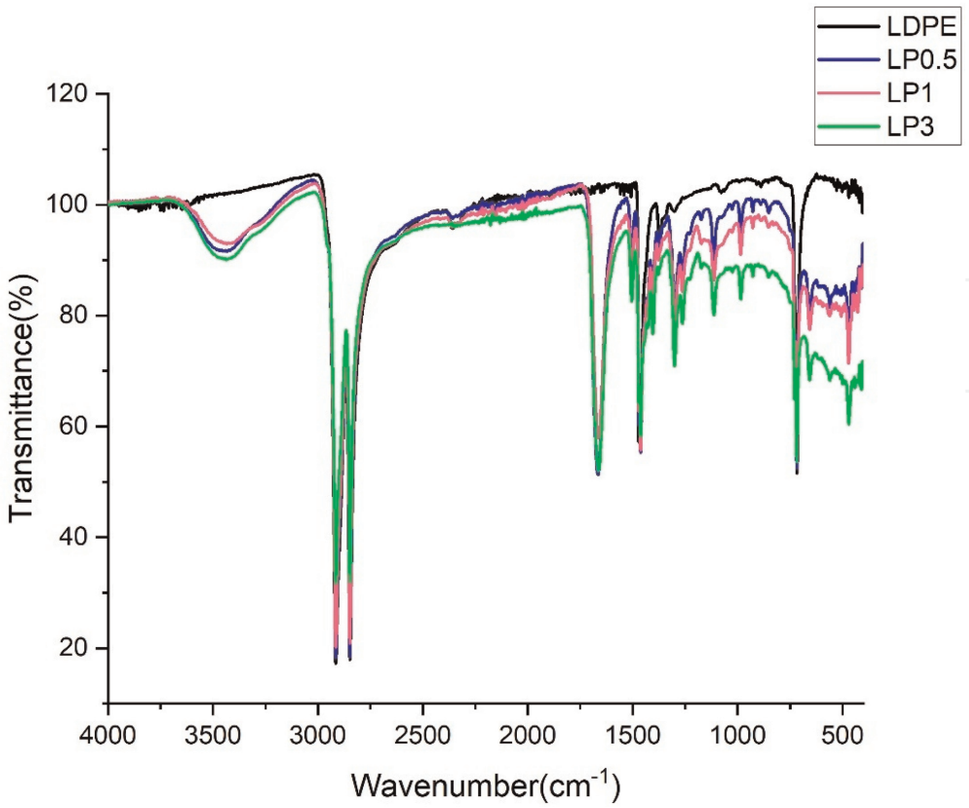

Figure 4.
FT-IR Spectra of LDPE, $LP_{0.5}$, LP_1, and LP_3.

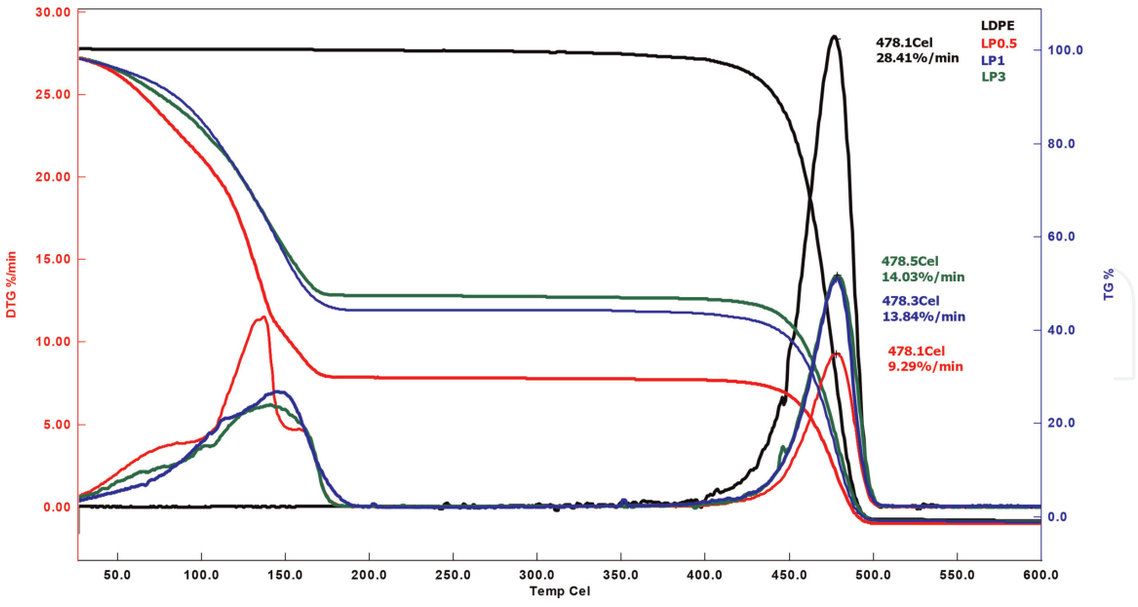

Figure 5.
TG-DTG thermogram of LDPE, $LP_{0.5}$, LP_1, and LP_3.

corresponding to the maximum decomposition temperature were examined, the value of pure LDPE was higher than that of blends. The amount of solvent remaining in the blends caused the DTG values to be lower.

	T_{max} (°C)	DTG of T_{max} *(%/min)*
LDPE	478.1	28.41
$LP_{0.5}$	478.1	9.29
LP_1	478.3	13.84
LP_3	478.5	14.03

Table 1.
TG-DTG data of LDPE and resulting blends.

3.3 DSC analysis of resulting blends

DSC measurements were performed by using TA DSC/250. DSC analyses of the blends were carried out starting from room temperature up to 250°C at a heating rate of 10°C/min. **Figure 6** shows the second heating of the DSC thermograms of LDPE blends doped with PANI.

Melting temperature (Tm), heat of fusion (ΔH), and degree of crystallinity values (X_c) were found from this thermogram and are given in **Table 2**. The heat of fusion was used to assess the samples' degree of crystallinity, X_c. Eq. (1) was used to calculate the crystallinity X_c (%) based on DSC data as follows:

$$X_c(\%) = \frac{\Delta H}{\Delta H^{\circ}} 100 \tag{1}$$

where ΔH° is the specific heat of melting of a perfect crystal of LDPE and ΔH° = 293 J/g has been utilized in this study [9]. PANI and LDPE are immiscible [10] so the melting temperature of LDPE does not appear to be significantly impacted by the amount of PANI. A decrease of approximately 1°C in melting temperature was observed while adding PANI to the LDPE matrix. However, when the PANI amount

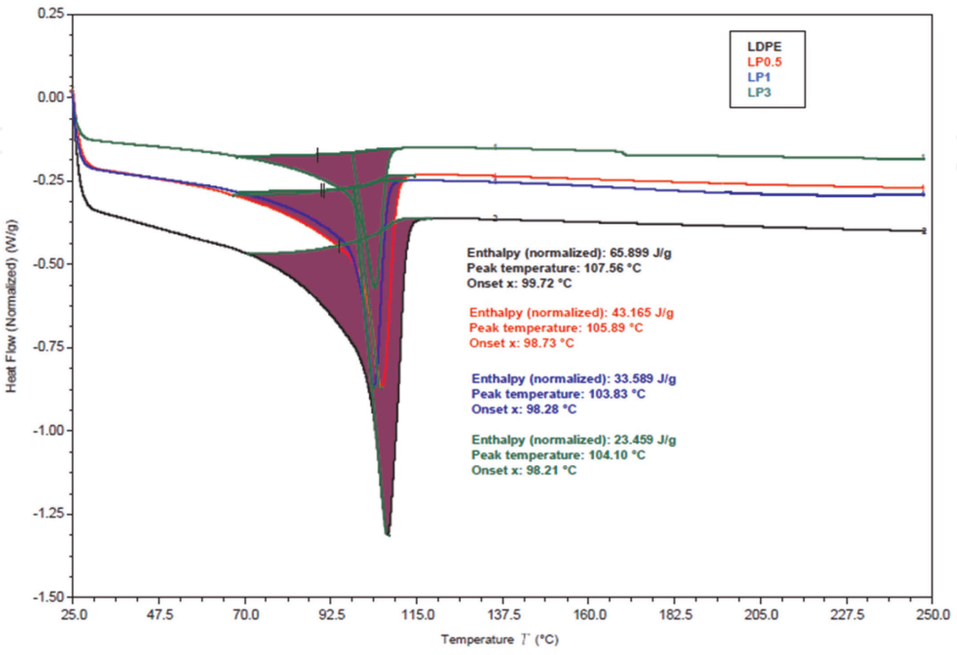

Figure 6.
DSC thermogram of LDPE, $LP_{0.5}$, LP_1, and LP_3.

	T_m	ΔH, j/g	X_c(%)
LDPE	99.7	65.9	22,5
$LP_{0.5}$	98.7	43.2	14.7
LP_1	98.3	33.6	11,5
LP_3	98.2	23.5	8.0

Table 2.
DSC data of LDPE and resulting blends.

in the blends increases, the degree of LDPE crystallinity significantly decreases. Because PANI is amorphous, the blends' amorphous phase will grow, which causes the percentage of crystallinity in the composites to gradually decrease as PANI concentration increases. Furthermore, the decrease in LDPE's crystallinity was brought on by the blends' increased PANI content. This indicates that PANI particles inhibit LDPE crystallization. For HDPE/LLDPE/PANI blends, identical results have been reported in the literature [11].

3.4 X-ray analysis of blends

X-ray diffraction patterns of the samples were taken with the PANalytical EMPYREAN XRD device. Diffraction patterns for all samples were taken from 10°–80° at a diffraction angle of 2Θ. **Figure 7** shows the X-ray diffraction pattern of LDPE blends doped with PANI of 3 wt%, 1 wt%, and 0.5 wt%. Ortho hexagonal, metastable monoclinic, and stable orthorhombic crystal forms make up commercial PE. The flat zigzag chain conformation is present in orthorhombic and monoclinic phases. Two distinct diffraction peaks at 2 Θ =21.27° (110) and 2 Θ =23.46° (200) of LDPE are seen in patterns that are consistent with the literature (**Table 3**) [12]. These peaks indicate that the LDPE used in this study has an orthorhombic structure.

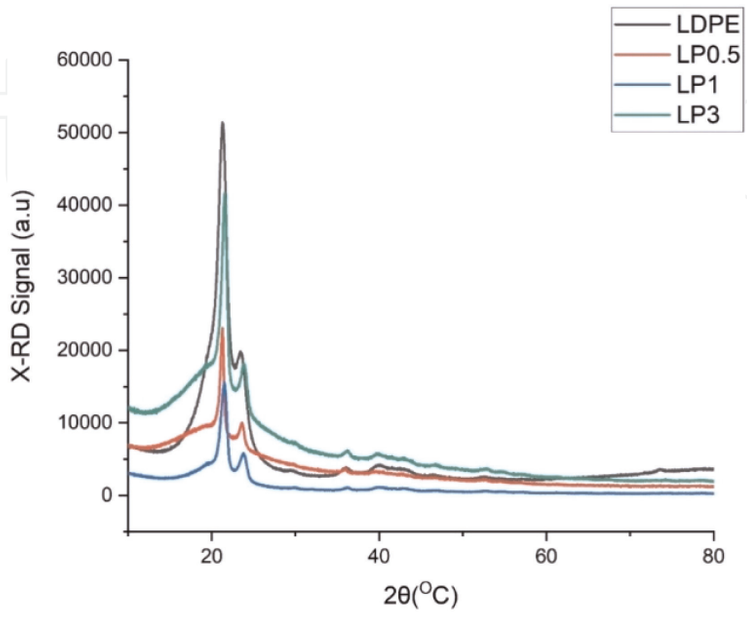

Figure 7.
X-ray diffraction pattern of LDPE, $LP_{0.5}$, LP_1, and LP_3.

Sample	$2\Theta_1$	$2\Theta_2$
LDPE	21.27	23.46
$LP_{0.5}$	21.28	23.61
LP_1	21.50	23.79
LP_3	21.55	23.85

Table 3.
X-ray diffraction of LDPE and resulting blends.

The addition of the PANI to the LDPE showed that the X-ray diffraction peaks at 2 Θ did not change much, which are given in **Table 3**, but blends' peak intensities indicated a slight decrease. Decreases in peak intensities can be attributed to decreases in crystallinity [13].

3.5 SEM images of resulting blends

SEM images were taken at different magnifications to examine the morphological features of the resulting blends. Images were obtained with the ZEISS GEMINI 500 SEM instrument. SEM image of pure LDPE in film form is given in **Figure 8**. According to the morphological images, the film surfaces of pure polyolefins are smooth.

SEM images of the resulting blends are given in **Figure 9**. Here, it was seen that when 0.5 wt% PANI is added to completely smooth pure LDPE, solid particles begin to cluster. These images support the decrease in mechanical properties. When the amount of PANI is increased to 1%, these clusters increase even more and appear as nodules. However, the LDPE blend, which is doped with 3 wt% PANI, shows regular structures and micro-channels resembling hexagons. This can lead to an increase in the conductivity of the structure. Clusters are also seen in the SEM image of the LP_3 blend.

3.6 Conductivity measurements of PANI, LDPE, and resulting blends

The conductivities of the synthesized materials were measured in the film form with a Keithley 2400 electrometer. According to the literature, it is seen that the

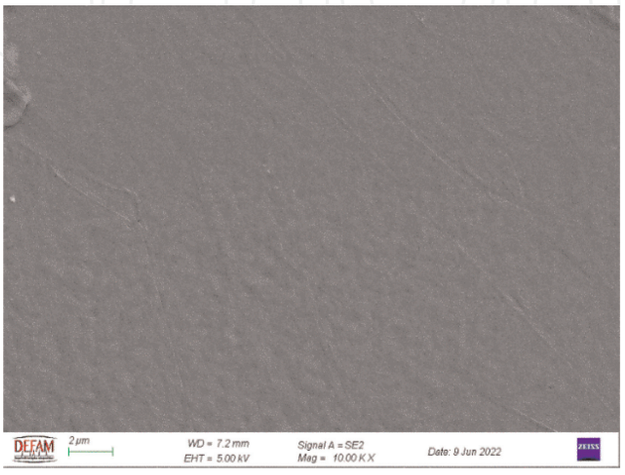

Figure 8.
SEM Image of LDPE in film form.

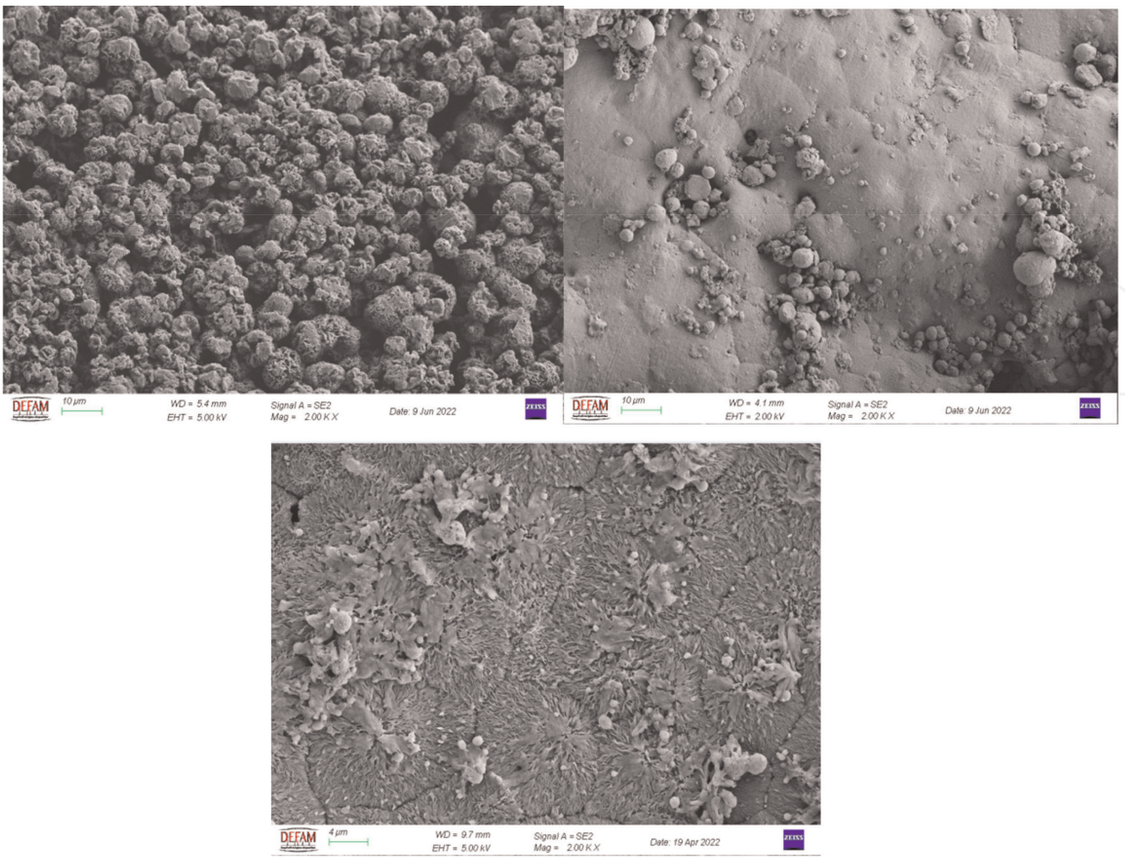

Figure 9.
SEM Images of $LP_{0.5}$, LP_1, and LP_3 blends.

conductivity value tends to increase as the conductive additive is added [14]. When the conductivity measurements are examined, it is seen that the conductivity of LDPE with a conductivity of 3.6 10^{-11} S cm^{-1} increases as PANI is added (**Figure 10**).

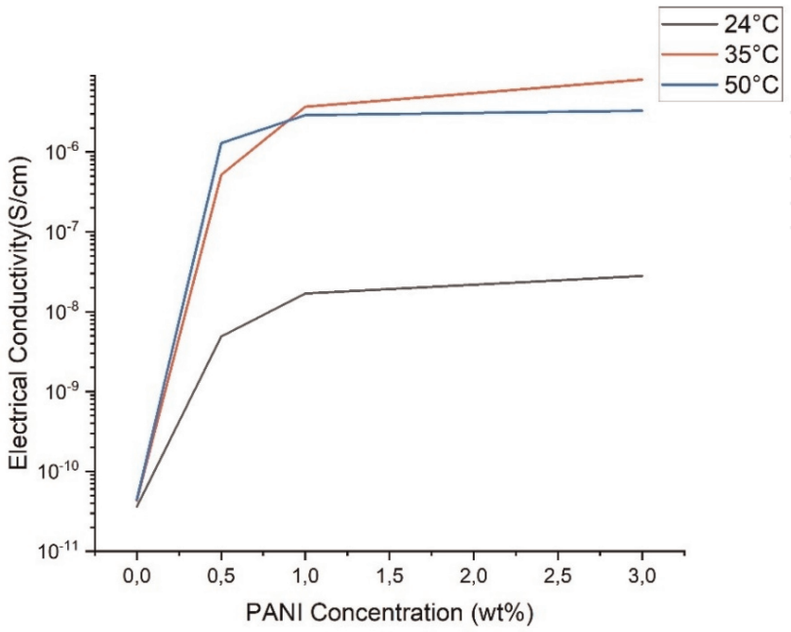

Figure 10.
Conductivity measurements of resulting blends and pure materials.

Sample	Conductivity (24°C, Scm^{-1})	Conductivity (35°C, Scm^{-1})	Conductivity (50°C, Scm^{-1})	References
PANI	$4.5*10^{-6}$	$6.6*10^{-6}$	$3.1*10^{-5}$	This work
LDPE	$3.6*10^{-11}$	$4.3*10^{-11}$	$4.4*10^{-11}$	This work
%0.5 PANI-LDPE	$4.9*10^{-9}$	$5.2*10^{-7}$	$1.3*10^{-6}$	This work
% 1 PANI-LDPE	$1.7*10^{-8}$	$3.7*10^{-6}$	$2.9*10^{-6}$	This work
% 3 PANI-LDPE	$2.8*10^{-8}$	$8.1*10^{-6}$	$3.3*10^{-6}$	This work
% 40 PANI-LLDPE-HDPE	$3.7*10^{-6}$	—	—	[16]
% 5 PANI-LLDPE-HDPE	$2.8*10^{-11}$	—	—	[16]
% 10 PANI-LLDPE-HDPE	$5.3*10^{-11}$	—	—	[16]
% 15 PANI-LLDPE-HDPE	$5.5*10^{-11}$	—	—	[16]
% 20 PANI-LLDPE-HDPE	$1.2*10^{-10}$	—	—	[16]
% 40 PANI-LLDPE-HDPE	$3.7*10^{-6}$	—	—	[16]
% 2 PANI/DBSA-LDPE-EVA	10^{-9}	—	—	[17]
% 20 PANI/DBSA-LDPE-EVA	10^{-5}	—	—	[17]
%5 NR/PANI-LLDPE	$3.38*10^{-15}$	—	—	[7]
%10 NR/PANI-LLDPE	$6.94*10^{-15}$	—	—	[7]
%15 NR/ PANI-LLDPE	$1.19*10^{-14}$	—	—	[7]
%20 NR/PANI-LLDPE	$1.93*10^{-14}$	—	—	[7]
%10 PANI-HDPE-stearic acid	$7.26*10^{-10}$	—	—	[18]
%10 PANI-HDPE	$3.34\ 10^{-17}$	—	—	[18]
%5 PANİ/DBSA-LDPE	10^{-3} S/cm	—	—	[15]

Table 4.
Conductivity measurements of resulting blends, pure materials, and blends in literature.

It is also seen in the literature [15] that those materials with a conductivity value of 10^{-6}–10^{-11} $S.cm^{-1}$ can be used as antistatic materials. The conductivity value of the blends we obtained varies between 10^{-6} and 10^{-9} $S.cm^{-1}$. Therefore, all resulting blends can be used as antistatic material.

The conductivities of resulting blends and pure materials at three different temperatures and the conductivities of previously polyaniline /polyaniline blends are given in **Table 4**. In the literature, it can be observed that previous studies have not achieved better conductivity values with the addition of such a small amount of PANI as we have.

3.7 Electrostatic charge dissipation (ESD) analysis of resulting blends

Electrostatic charge dissipation (ESD) is one of the challenges that have lately emerged with the rise of the electronics sector. Particularly, ESD is responsible for 60% of the damages to integrated circuits [19]. A viable solution to this issue is to incorporate semiconductor materials into the materials that are frequently utilized in the sector. The simplest technique to determine whether a material can retain a charge is to apply a charge to it and observe how quickly it dissipates. Corona charging offers

a quick, dependable, non-contact method for controlling the magnitude and polarity of charge deposits on any surface [20]. ESD applications of resulting blends were performed by Static Decay Meter, (Electro-tech Systems, USA, model 406D) and Charge Decay Time Analyzer (JCI 155v6, John Chubb Instrument, UK). The different positive (3, 6, and 9 kV) and negative corona voltages (−3, −6, and − 9 kV) at room temperature were applied to the surface of the resulting blends. We determine the dissipation time of static charge accumulation on the surface of the resulting blends. Firstly, pure LDPE ESD analysis was carried out. The LDPE surface was seen to accept extremely high surface voltages in both high negative and positive polarities of charge decay time curves. As predicted, static charge dissipation time (up to 300 seconds) for aggregation on the surface of LDPE could not be measured. The results obtained from the measurements are summarized in **Table 5**.

The performance of the ESD control material is dependent on its duration of static charge dissipation. ESD performance is based on either *i*-) the charge decay time of 1/e, which is equal to around 37% of the voltage value, or *ii*-) the charge decay time of 10% of the voltage value. Therefore, 1/e and 10% cut time standards require that the surface static load of a good ESD control material should be smaller than 1 and 2 s [21]. Considering the performance of different corona voltages of $LP_{0.5}$ blend as given in **Table 6**, the blend at -3 kV, 3 kV, and 6kVcorona voltage, according to the 1/e criterion (1/e time:

Corona voltage *(V)*	Corona time *(s)*	Surface humidity *(%RH)*	Surface temperature *(°C)*	Surface voltage *(V)*	1/e time *(s)*	%10 Cut-off time *(s)*	Surface charge *(nC)*	Capacitance
−9000	0.030	36.2	28.8	−2131.4	—	—	−57.3	11.56
−6000	0.030	34.7	29.8	−1252.0	—	—	−53.20	18.25
−3000	0.008	34.6	29.1	−425.8	—	—	−1.82	1.85
3000	0.008	33.6	28.2	−152.3	—	—	−2.034	5.703
6000	0.030	33	27.5	1731.4	—	—	−0.24	0.07
9000	0.030	32.9	27.2	1802.6	—	—	59.56	14.19

"-" means not determined.

Table 5.
Polarity values of pure LDPE at different corona voltages.

Corona voltage *(V)*	Corona time *(s)*	Surface humidity *(%RH)*	Surface temperature *(°C)*	Surface voltage *(V)*	1/e time *(s)*	%10 Cut-off time *(s)*	Surface charge *(nC)*	Capacitance
−9000	0.030	36.8	28.2	−135.1	9.307	27.213	−1373.96	4363.90
−6000	0.030	36.2	29.8	−96.6	34.401	—	−487.02	2164.41
−3000	0.030	33	29.8	−13.6	0.134	0.248	−37.80	1191.41
3000	0.020	32.2	22.4	−707.0	1.025	2.361	—	—
6000	0.020	32.4	22.7	−690.6	1.022	2.354	—	—
9000	0.030	36.1	26.2	127.9	12.934	—	629.95	2116.63

"-" means not determined.

Table 6.
ESD values of $LP_{0.5}$ blend at various corona voltages.

0.134 s for −3 kV; 1/e time: 1.025s for 3 kV, 1/e time: 1.022 s for 6 kV), could be used as ESD control material. Also, the cut-off time of the so-called blend was about below 2 s (% 10 cut-off time: 0.248 s for −3 kV; %10 cut-off time: 2.361 s for 3 kV, %10 cut-off time: 2.354 s for 6 kV). As a result, at -3 kV, 3 kV, and 6 kV Corona voltage, LP0.5 blend could be used as ESD control material.

The performance of different corona voltages of LP_1 blend, as given in **Table 7**, the blend at 3 kV corona voltage (1/e time: 1.025s; %10 cut-off time: 2.361 s) could be used as ESD material according to the 1/e and %10 cut-off time criterion.

Considering the performance of different corona voltages of LP_3 blend, as given in **Table 8**, the blend at -3 kV, 3 kV, and 6 kV Corona voltage, according to the 1/e criterion (1/e time: 0.115 s for −3 kV; 1/e time: 1.022 s for 3 kV, 1/e time: 1.010 s for 6 kV), could be used as ESD control material. Also, the cut-off time of the so-called blend was about below 2 s (%10 cut-off time: 0.256 s for −3 kV; %10 cut-off time: 2.361 s for 3 kV, %10 cut-off time: 2.292 s for 6 kV). As a result, at -3 kV, 3 kV, and 6 kV Corona voltage, LP_3 blend could be used as ESD material.

Corona voltage *(V)*	**Corona time *(s)***	**Surface humidity *(%RH)***	**Surface temperature *(°C)***	**Surface voltage *(V)***	**1/e time *(s)***	**%10 Cut-off time *(s)***	**Surface charge *(nC)***	**Capacitance**
−9000	0.030	35.8	28.5	−991.2	—	-	−706.56	306.09
−6000	0.030	35.2	29.8	−550.6	—	—	−260.46	203.11
−3000	0.029	32.7	30.4	−249.6	—	—	−31.75	54.63
3000	0.020	32.4	22.4	−700.8	1.025	2.361	—	-
6000	0.030	34.8	28.2	329.6	23.213	23.275	6.61	8.61
9000	0.030	36.6	26.5	1021.9	35.401	35.526	386.42	162.38

"-" means not determined.

Table 7.
ESD values of LP_1 blend at various corona voltages.

Corona voltage *(V)*	**Corona time *(s)***	**Surface humidity *(%RH)***	**Surface temperature *(°C)***	**Surface voltage *(V)***	**1/e time *(s)***	**%10 Cut-off time *(s)***	**Surface charge *(nC)***	**Capacitance**
−9000	0.030	36.8	28.2	−504.0	—	—	−293.18	249.77
−6000	0.030	36.0	29.8	−410.0	—	—	−100.99	105.77
−3000	0.030	33.1	29.8	−13.7	0.115	0.256	−33.97	1064.89
3000	0.020	32.5	22.7	−695.7	1.022	2.361	—	—
6000	0.020	32.4	22.7	−171.4	1.010	2.292	—	—
9000	0.030	36.7	26.2	454.5	—	—	152.65	144.24

"-" means not determined.

Table 8.
ESD values of LP_3 blend at various corona voltages.

3.8 DMA analysis of LDPE and resulting blends

DMA analysis of LDPE and resulting blends was performed by the TA Q800 DMA instrument with a ramp force rate of 1 N/min at 25 °C. The applied frequency was 1 Hz, and a tensile film clamp was used to obtain a stress-strain curve. Stress-strain curves of LDPE and resulting blends with different PANI contents are given in **Figure 11**.

The mechanical behavior of LDPE was significantly altered by the addition of PANI. Since the PANI is polar and the PE is nonpolar, it may be inferred that there is no adhesion between the phases and that the addition of PANI has a detrimental effect on the mechanical characteristics of the polymer matrix. In conductive polymers, a conjugated carbon chain is made up of alternating single and double bonds (π bonds) which are strongly polarized, delocalized, and electron-dense [22]. Due to the conjugated carbon chain of PANI, the aggregation of PANI particles makes it difficult to establish a proper filler distribution in the PE matrix. Therefore, the mechanical properties of blends decrease. There is a decrease in the mechanical strength of resulting blends summarized in **Table 9**.

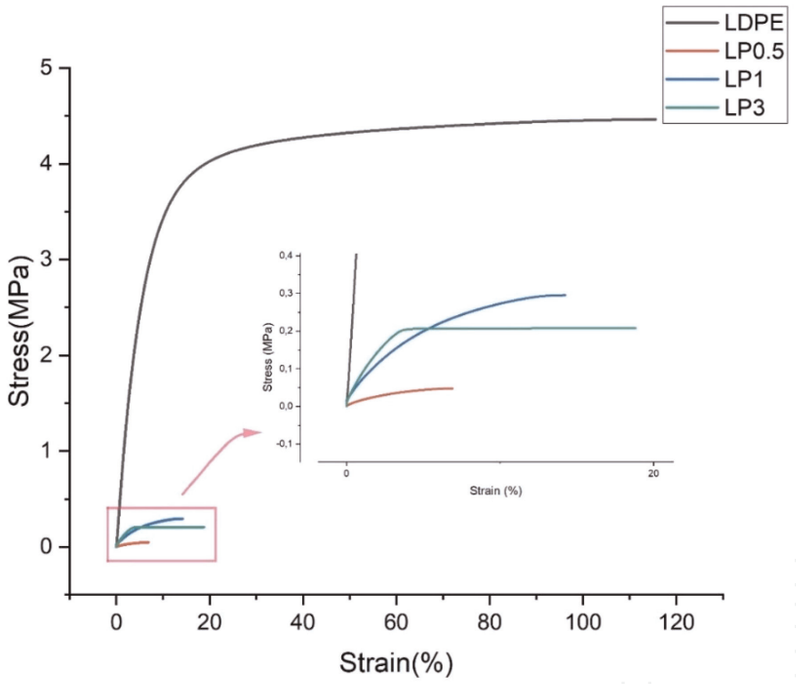

Figure 11.
Stress-strain curves of LDPE, $LP_{0.5}$, LP_1, and LP_3.

Sample	Stress (MPa)	Strain (%)
Pure LDPE	4.46	115.57
$LP_{0.5}$	0.05	6.91
LP_1	0.29	14.24
LP_3	0.21	18.81

Table 9.
Stress-Strain results of LDPE and resulting blends.

4. Conclusion

LDPE/PANI blends were successfully prepared by the solution blending method using a mixture of NMP and toluene. By using FTIR analysis, specific vibration bands of PANI and LDPE were identified. The presence of specific vibration bands in both materials and the absence of other new formation peaks are proof that these materials are physically blended. Thermal gravimetric analysis of resulting blends showed two-step weight loss behavior. The first one is due to solvent evaporation and the decomposition of LDPE also causes the second degradation. It was observed that the temperature values corresponding to the highest degradation rate of pure LDPE and $LP_{0.5}$, LP_1, and LP_3 were around 478°C. This indicates that there is no change in thermal stability. Since LDPE and PANI are immiscible, it was found that adding PANI to the blends did not have much effect on the T_m values but decreased the degree of LDPE crystallinity. Since PANI is amorphous, the amorphous phase of the resulting blends expands, which means that as PANI concentration rises, the percentage of crystallinity in the composites progressively decreases. It was also evident from the SEM images that PANI particles tended to gather to one side. This tendency makes it difficult for PANI to disperse well in LDPE. This aggregation is the reason why the crystallinity percentage and even mechanical properties decrease. Besides these clusters of solid particles, the LDPE blend, which is doped with 3 wt % PANI, shows regular structures and micro-channels resembling hexagons. According to the stress-strain results, there is a decrease in mechanical properties. When X-ray diffraction patterns are examined, two distinct diffraction peaks like those of LDPE are seen. As the concentration of PANI increases in LDPE, the X-ray diffraction peaks shift toward higher angles. The diffraction peak shifts can be attributed to a decrease in the crystallinity. These results support the crystallinity values calculated from DSC. The conductivity values of the blends were found to be between 10^{-9} and 10^{-6} $S.cm^{-1}$, therefore, all blends can be used as antistatic material. ESD analyses were performed for antistatic applications. At room temperature, different positive (3, 6, and 9 kV) and negative corona voltages (−3, −6, and − 9 kV) were applied to the surface of the resulting blend. The dissipation time of static charge accumulation on the surface of the blends was determined. At −3 kV, 3 kV, and 6 kV Corona voltage, $LP_{0.5}$ blend and LP_3 blend could be used as ESD control material. LP_1 blend at 3 kV corona voltage could be used as ESD material according to the 1/e and %10 cut-off time criterion.

Acknowledgements

This study is part of the research conducted by the first author toward a PhD dissertation. The Manisa Celal Bayar University Applied Science and Research Center provided analysis, and the authors are appreciative of the financial support (Project number 2020-116) from the Manisa Celal Bayar University Scientific Research Project Coordination Unit.

DOI: http://dx.doi.org/10.5772/intechopen.115297

IntechOpen

Author details

Ayse Nur Ozkan[1], Kamil Sirin[2] and Fatih Dogan[3]*

1 Applied Science Research Center, Manisa Celal Bayar University, Manisa, Turkey

2 Faculty of Science and Arts, Department of Chemistry, Celal Bayar University, Manisa, Turkey

3 Education Faculty, Department of Chemistry Education, Çanakkale Onsekiz Mart University, Çanakkale, Turkey

*Address all correspondence to: fatihdogan@comu.edu.tr

IntechOpen

© 2024 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. CC BY

References

[1] Sogancioglu M, Yel E, Ahmetli G. Pyrolysis of waste high-density polyethylene (HDPE) and low-density polyethylene (LDPE) plastics and production of epoxy composites with their pyrolysis chars. Journal of Cleaner Production. 2017;**165**:369-381

[2] Hideki Shirakawa B, Louis EJ, Macdiarmid AG, Chiang CK, Heeger AJ. Synthesis of Electrically Conducting Organic Polymers: Halogen Derivatives of Polyacetylene, (CH)x. Journal of the Chemical Society, Chemical Communications. 1977;**16**:578-580

[3] Abraham D, Bharathi A, Subramanyam SV. Highly conducting polymer blend films of polyaniline and nylon 6 by cosolvation in an organic acid. Polymer. 1996;**37**:5295-5299

[4] Ivanov S, Mokreva P, Tsakova V, Terlemezyan L. Electrochemical and surface structural characterization of chemically and electrochemically synthesized polyaniline coatings. Thin Solid Films. 2003;**441**:44-49

[5] Zhao Y, Yao W, Wang Y, Wang Q, Lou F, Guo W. High-performance antistatic acrylic coating by incorporation with modified graphene. Journal of Materials Research. 2019;**34**: 510-518

[6] Bhandari H, Singh S, Choudhary V, Dhawan SK. Conducting films of poly (aniline-co-1-amino- 2-naphthol-4-sulfonic acid) blended with LDPE for its application as antistatic encapsulation material. Polymers for Advanced Technologies. 2011;**22**:1319-1328

[7] Nand AV, Ray S, Travas-Sejdic J, Kilmartin PA. Characterization of antioxidant low-density polyethylene/ polyaniline blends prepared via extrusion. Materials Chemistry and Physics. 2012;**135**:903-911

[8] Koul S, Chandra R, Dhawan SK. Conducting Polyaniline Composite for ESD and EMI at 101 GHz [Internet]. 2000. Available from: www.elsevier.nl/ locate/polymer

[9] Li D, Zhou L, Wang X, He L, Yang X. Effect of crystallinity of polyethylene with different densities on breakdown strength and conductance property. Materials. 2019;**12**:1746

[10] Passador FR, de Faria PV, Backes EH, Montanheiro TLA, Montagna LS, de Souza PS, et al. Thermal, mechanical, and electromagnetic properties of LLDPE/PANI composites. Polymer Bulletin. 2017;**74**:2701-2717

[11] Valadão de Faria P, Backes EH, Montagna LS, de Souza Pinto S, Pessan LA, Rezende MC, et al. Effect of PANI on thermal, mechanical, and electromagnetic properties of HDPE/ LLDPE/PANI composites. Materials Research. 2018;**21**:1-9

[12] Depan D, Chirdon W, Khattab A. Morphological and chemical analysis of low-density polyethylene crystallized on carbon and clay nanofillers. Polymers (Basel). 2021;**13**:1558

[13] Bhadra J, Al-Thani NJ, Madi NK, Al-Maadeed MA. High-performance sulfonic acid doped polyaniline–polystyrene blend ammonia gas sensors. Journal of Materials Science: Materials in Electronics. 2016;**27**:8206-8216

[14] Omastova M, Pionteck J, Kosina S. Preparation and Characterizatıon of Electrically Conductive Polypropylene/ Polypyrrole Composites. European Polymer Journal. 1996;**32**:681-689

[15] Joelma M, Cardoso R, Fogliato M, Lima S, Lenz DM. Polyaniline Synthesized with Functionalized Sulfonic Acids for Blends Manufacture. Materials Research. 2007;**10**:425-429

[16] Oliveira LB, Graeff CZ, Faria PV, Backes EH, Cristovan FH, Passador FR. Preparation and characterization of conductive HDPE/LLDPE/Polyaniline blends. In: AIP Conf Proc. Graz, Austria: American Institute of Physics Inc.; 2016

[17] Zhang QH, Wang XH, Chen DJ, Bin JX. Electrically conductive, melt-processed ternary blends of polyaniline/dodecylbenzene sulfonic acid, ethylene/vinyl acetate, and low-density polyethylene. Journal of Polymer Science Part B: Polymer Physics. 2004;**42**:3750-3758

[18] Vanga-Bouanga C, Heid TF, Frechette MF, David E. Influence of Interface on the Dielectric Response, Electrical and Thermal Conductivity of High-Density Polyethylene Based Composites. In: 2015 Annual Report Conference on Electrical Insulation and Dielectric Phenomena. Ann Arbor, MI, USA: IEEE Conference on Electrical Insulation and Dielectric Phenomena (CEIDP); 2015

[19] Hwang Y-C. Electrostatic Discharge and Electrical Overstress Failures Of Non-Sılıcon Devıces. [PhD dissertation]. Graduate School of the University of Maryland at College Park; 2005

[20] Saini P, Choudhary V. Electrostatic charge dissipation and electromagnetic interference shielding response of polyaniline-based conducting fabrics. Indian Journal of Pure & Applied Physics. 2013;**51**:112-117

[21] Doğan F, Şirin K, Kolcu F, Kaya İ. Conducting polymer composites based on LDPE doped with poly (aminonaphthol sulfonic acid). Journal of Electrostatics. 2018;**94**:85-93

[22] Namsheer K, Rout CS. Conducting polymers: a comprehensive review on recent advances in synthesis, properties, and applications. RSC Advances: Royal Society of Chemistry. 2021;**11**:5659-5697