Anti-Electrostatic Properties of Various Types of Ethylene Ionomers

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ABSTRACT: The relationship between ionomer structure and surface resistivity (ρ_s) was studied for Na, K, Cs, Mg, and Zn ionomers prepared from poly(ethylene-*co*-methacrylic acid) (EMAA) and poly(ethylene-*co*-acrylic acid) (EAA). The study revealed that only ionomers highly neutralized with alkali metal cations exhibit anti-electrostaticity and the origin of ionic conduction was assumed to result from the transfer of water-coordinated metal cations. The method of mixing high- and low-acid ionomers was found to be effective in reducing the magnitude of moisture absorption while maintaining the anti-electrostaticity. Blends of a potassium ionomer with a wide variety of thermoplastics were also prepared to evaluate the possibility of using ethylene ionomers as anti-electrostatic additives. Interestingly, the effect of the potassium ionomer upon ρ_s of the blends differed by the type of the thermoplastics, suggesting that how the ionomer phase distributes over the matrix may be influenced by local interactions between ionomer and polymer matrix phases.

KEY WORDS Ethylene Ionomer / Alkali Metal Salt / Anti-Electrostatic Property / Surface Resistivity / Moisture Uptake /

Ionomers are defined as polymers consisting of hydrophobic backbones and a small amount of ionic moieties attached to or at the terminal of the polymer backbones. Despite the presence of ionic groups, there is little difference in the electrical properties between ionomers and their host polymers so that ionomers are generally considered to be an electrical insulator. For example, volume resistivity at 23°C and 50% relative humidity was 4.07×10^{16} and $17.2 \times 10^{16} \Omega \cdot \text{cm}^{-1}$ for an ethylene ionomer and a low-density polyethylene, respectively.¹ This indicates that metal cations of ethylene ionomers are tightly bound to carboxylate ions that are covalently bonded to the polymer backbones.

For a number of years, we have been in-

terested in the structure and properties of ethylene ionomers, and more emphasis has currently been placed on their structural changes caused by water absorption.²⁻⁴ Our studies revealed that hydrophilic ionic groups are strong absorption sites of water molecules and water absorption preferentially affects the structure of the ionic aggregates. Such plasticizing effects usually create unfavorable impacts on the physical properties due to the softening of rigid ionic cross-links. From the dc conductivity study on the ethylene ionomers, we also found that water absorption influences dc conductivity of ethylene ionomers; dc conductivity at ambient temperature became more than 10 times with an increase of the water content from 0.45 to 1.1 wt%.⁵ The data have

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drawn our attention since the results suggest the possibility of using hydrated ionomers as electro-conductive or anti-electrostatic thermoplastics. These thermoplastics have been practically utilized for anti-electrostatic packages and cases. Most of the current materials are produced by introducing electro-conductive filler or anti-electrostatic surfactant into thermoplastics. However, those types of thermoplastics have the deficiency of poor transparency or blooming of surfactant on the surface of finished products. The application of ethylene ionomers as transparent, electro-conductive thermoplastics is proposed by Inazawa *et al.*,⁶ where the sodium and potassium ionomers were claimed to provide excellent surface conductivity enough to overcome the electrostatic accumulation if the ionomers contained an ion content of greater than 1.3 mol kg^{-1} polymer. However, their practical use has been hampered by the fact that a large amount of moisture uptake is inherent in these ionomers, which readily makes it difficult to be conventionally processed.

In this paper, we have investigated the relationship between ionomer structure and the anti-electrostatic properties, and have described an attempt to reduce moisture uptake to the extent of practically acceptable levels. An investigation into the use of ethylene ionomers as anti-electrostatic additives for a wide variety of thermoplastics is also the subject of this paper.

EXPERIMENTAL

Preparation of Ethylene Ionomers

The starting materials of poly(ethylene-co-methacrylic acid) (EMAA) and poly(ethylene-co-acrylic acid) (EAA) were from Du Pont-Mitsui Polychemicals Co., whose methacrylic and acrylic acid content ranges from 1.3 to 12.2 mol%. Various metal (Na, K, Cs, Mg, and Zn) salts of EMAA and EAA were prepared by a melt reaction of EMAA or EAA with

stoichiometric quantity of cation sources (*e.g.*, metal carbonates, metal acetates, and metal hydroxides) in a single-screw extruder at 473–523 K and 35 rev min^{-1} . The ionomers extruded were cut into pellets. In the case of producing high- and low-acid ionomer mixtures, the acid copolymers were dry blended at an indicated ratio and then fed into the extruder for the melt reaction. We delineate the samples as E/xMAA-yM or E/xAA-yM, where x, y, and M are acid content (mol%), the degree of neutralization, and metal cation, respectively.

The pellet samples were compression-molded into 1- and 3-mm-thick sheets at 15 MPa and 453 K and then cooled to room temperature at a cooling rate of about 30 K min^{-1} . All the sheets were transparent, showing no signs of unreacted metal salts. The formation of metal carboxylate was confirmed by the infrared spectra. The sheets were then kept in a moisture-barrier bag for subsequent measurement of surface resistivity and moisture absorption.

Preparation of Blends of Ionomer with Thermoplastics

Thermoplastics used for the investigation into the use of ionomers as anti-electrostatic additives were purchased from several companies; ABS (Sevian V500) from Denka, polyamide-6 (PA-6; Amiran CM-1017C) and poly(butylene terephthalate) (PBT; 1401) from Toray, poly(ethylene terephthalate) copolymer (PET; Kodar G-6763) from Eastman Chemical, poly(methyl methacrylate) (PMMA; Del-pet 560F) from Asahi, polypropylene (PP; Hipol L840) and low-density polyethylene (LDPE; Mirason 10P) from Mitsui Petrochemical, and polystyrene (PS; Topolex GP525) from Mitsui Toatsu. Blends of 10 wt% of a potassium ionomer, E/9.4AA-0.80K, with those thermoplastics were prepared using a Laboplastmill of Toyoseiki Company with the rotor turning at 60 rev min^{-1} for 10 min under a constant flow of dry nitrogen. The melt temperature of the blends was controlled at

453–533 K, depending upon the type of the thermoplastics. At the end of 10 min, the blends were immediately removed, compression-molded at 453–533 K into 2-mm-thick sheets under 15 MPa pressure and kept in a moisture-barrier bag for subsequent measurement of surface resistivity.

Measurements

Surface resistivity (ρ_s) of 1- or 2-mm-thick sheets was measured using a high resistance meter, Hiresta-IP of Mitsubishi Petrochemicals Co., whose probe consists of a circular electrode of 5.9 mm diameter and a ring electrode of 11.0 mm inner-diameter. The resistivity correction factor of this equipment is 10.07. The sheets were kept at 298 K and 60% relative humidity (RH) for 4 days before measurements. We consecutively measured ρ_s of some of the samples for two weeks and found that ρ_s seemed to reach a constant value at 3–4 days of the aging. In our previous work, it was found that equilibrium water absorption was achieved within 24 hours for 0.05-mm-thick films, while the weight change of sheets of *ca.* 0.5-mm thickness indicated that it required more than 1 month to obtain the complete equilibrium.² Therefore, the surface of the sample sheets probably reached an equilibrium water content as quickly as a very thin film did. It was found that the results obtained are extremely subject to the measurement conditions such as temperature, humidity, sample thickness, aging time, and initial water content. Therefore, we tried to carefully treat the samples under the same conditions in this experiment. Repeated measurements indicated that the precision is roughly $\pm 3\%$ of the logarithm of ρ_s (e.g., $1.5\text{--}6.5 \times 10^{10} \Omega$).

Two types of experiments were conducted to determine moisture absorption behaviors: Samples for the measurements of equilibrium moisture content were 3-mm-thick sheets (100-mm length, and 20-mm width), which were stored at room temperature and 40–50% RH for about two years. Samples for the

moisture uptake tests were also 3-mm-thick sheets, which were stored at room temperature and 60% RH for 1 month. The water content of those samples was determined from the weight loss after being dried in a 473 K oven for 10 min, where the weight changes were measured using a Mettler AT400 balance with a sensitivity of 10^{-4} g. No conversion of acid to acid anhydride during the drying process was confirmed by the infrared spectra.

RESULTS AND DISCUSSION

Surface Resistivity (ρ_s) of Ethylene Ionomers

In general, plastics with ρ_s in the magnitude of $10^{12} \Omega$ or less are regarded to be anti-electrostatic because most of these plastics do not accumulate the static charges in contact with other materials. Table I summarizes ρ_s results of Na, K, Cs, Mg, and Zn ionomers prepared from EMAA. As shown in this table, the ρ_s values remarkably depend upon the type of metal cations and cation content: Low values of ρ_s are seen only for ionomers highly neutralized with alkali-metal cations. The Cs ionomer, E/7.5MAA-0.60Cs, provides excellent anti-electrostaticity even at a relatively small cation content, while the Na ionomer,

Table I. Surface resistivity of metal salts of EMAA

Ionomer	Cation content	Surface resistivity ^a
	mol kg ⁻¹ ionomer	Ω
E/12.2MAA-0.67K	2.34	5×10^6
E/12.2MAA-0.70Na	2.47	1×10^{11}
E/12.2MAA-0.60Zn	2.10	$> 1 \times 10^{12}$
E/7.5MAA-0.71K	1.65	2×10^7
E/7.5MAA-0.60Cs	1.39	1×10^6
E/7.5MAA-0.80Zn	1.86	$> 1 \times 10^{12}$
E/5.4MAA-0.81K	1.42	7×10^{10}
E/5.4MAA-0.73K	1.27	2×10^{11}
E/5.4MAA-0.90Mg	1.58	$> 1 \times 10^{12}$

^a Measured at 296 K and 60% RH.

Figure 1. Plots of the equilibrium moisture content at room temperature and at 40–50% relative humidity for various metal-cation salts of E/5.4MAA as a function of the degree of neutralization.

E/11.2MAA-0.70Na, shows a low level of the electrostatic discharge even at a high cation content. In contrast to the alkali metal ionomers, the Mg and Zn ionomers do not present any anti-electrostaticity even at very high cation contents. In Figure 1 changes of an equilibrium moisture content with the degree of neutralization are shown for Na, K, Mg, and Zn salts of E/5.4MAA taken at room temperature and 40–50% RH. The marked effect of the type of metal cations is evident, showing that the equilibrium moisture content increases in the order $K > Na > Mg > Zn$. This cation dependence can be attributed to the affinity of the metal salts for water molecules as discussed in our previous paper.⁴ The coincidence of the order of the cation dependence between ρ_s and equilibrium moisture content is taken as evidence that water molecules absorbed certainly contribute to ionic conduction. In addition, it is assumed that hydrated and dissociated cations mainly act as charged carriers in the current system. Therefore, the dissociation energy of the metal carboxylate should strongly influence surface resistivity of the alkali cation ionomers at

relatively low cation contents. This might be the reason why a highly neutralized Na salt of EMAA exhibited large surface resistivity even though its moisture absorption was expected to be relatively high. Tsuchida *et al.* reported similar cation dependence, where at low ion concentration, the conductivity of poly[oligo-(oxyethylene) methacrylate]-MSCN hybrid films decreased in the order $K > Na > Li$.⁷ They also attributed this observation to the dissociation energy of the added salts.

It should be emphasized that the equilibrium moisture content of the Na and K ionomers is remarkably neutralization-dependent. The moisture content is relatively small up to about 40% neutralization, but abruptly arises at higher degrees of neutralization. Hiraoka *et al.* reported similar changes of the equilibrium moisture content with neutralization for Na and K salts of poly(acrylic acid) taken at 298 K and 73% RH.^{8,9} They have proposed that the Na salts may have a hexa-coordinated structure, in which one Na can be coordinated by six oxygens, namely three carboxyl oxygen atoms. Above a neutralization of about 33%, some coordination sites may be apparently unoccupied, and become strong water absorption sites. Therefore, an increase of apparent unoccupied-coordination sites causes the rapid increase of moisture absorption above ~40% neutralization.

From the dynamic mechanical^{10–12} and dielectric¹³ relaxation studies, it is known that at about 40% neutralization, the Na salts of EMAA come to exhibit microphase separation of ionic aggregates from the polymer matrix, which is detected as the appearance of two individual relaxations assigned to a glass transition of both regions. In our speculation, the microphase separation should result from the aggregation of ionic groups and most acid groups that exist in the vicinity of Na cations, and therefore, the polymer matrix would scarcely contain acid and ionic groups. There is another evidence for the acid-coordination model: FTIR studies by Han *et al.*¹⁴ revealed

Figure 2. Plots of (○) surface resistivity and (●) moisture uptake for the K salts of EMAA as a function of the cation content. The acid content is indicated in mol% at the top of each dotted line.

that the alkali metal salts of EMAA exhibit peak shifting and band broadening of the carbonyl group vibration near 1698 cm^{-1} at higher degrees of neutralization. These changes are also attributed to the formation of the acid-base complexes which consist of the unneutralized carboxyl groups and alkali metal cations.

A series of the K ionomers was chosen to study the remaining parameters (*e.g.*, cation content, acid content, the type of acid group, and relative humidity). Figure 2 shows the effects of the cation content upon ρ_s and moisture uptake at 60% RH. These data were obtained from the K ionomers with MAA contents ranging 1.3–12.2 mol%. Evidently, ρ_s values are strongly related to the amount of cation present. The ρ_s value increased with decreasing the cation content, and a minimum amount of the cation content around 1.3–1.4 mol kg^{-1} polymer was at least needed to obtain an anti-electrostatic ionomer. In addition, ρ_s appeared to reach a lowest level when the cation content became greater than $\sim 2.0\text{ mol kg}^{-1}$ polymer. Figure 2 also shows that the moisture uptake is dependent upon a combination of the cation content and the degree of neutralization. The cation content appears to be a dominant contributor to the water absorption, but the degree of neutralization, which is related to the

amount of unoccupied-coordination sites, also influences the water absorption. Perhaps ρ_s is dependent upon the degree of neutralization, but its dependence is not as obvious as that of the water uptake.

We calculated the number of water absorbed per potassium cation, and found an interesting fact that the number for the anti-electrostatic ionomers was in the range of 1.7–2.8, while that for the electrostatic ionomers was in the range of 0.8–1.3. From these results, we can explain the electro-conductive behavior as follows: It is well known that ionic conductivity is a function of the number of charged carriers and the mobility of charged carriers. In the current system, water molecules absorbed into the ionic aggregates dissociate ionic salt groups, and above certain levels of water coordination, hydrated metal cations would become mobile and cause ionic conduction through the transfer of ions. Thus, hydrated and dissociated cations probably act as charged carriers in the current system, and the number of charged carriers should depend on the cation content, the dissociation energy of metal carboxylate, and the hydration to metal cations. Regarding the mobility of charged carriers, an increase of cation contents increases the number of ionic cross-links and causes significant restriction on molecular motions of the polymer backbone chains in the amorphous regions, resulting in the reduction of the mobility of charged carriers in those regions. Therefore, the balance between the increase of the number of charged carriers and the reduction of the mobility of charged carriers may be the reason why surface resistivity comes to exhibit a minimum value at high cation contents in Figure 2.

From Table II, it is easily understood that ρ_s of the K salts of EAA clearly depends upon the degree of neutralization as well as the cation content. E/8.9AA–0.60 K and E/6.4AA–0.80 K have the same cation content (1.67 mol kg^{-1}), but obviously a higher neutralization is favorable for lowering a ρ_s value. Moreover, from Figure 2 and Table II, σ_s of both

Table II. Surface resistivity of potassium salts of EAA

Ionomer	Cation content	Surface resistivity ^a
	mol kg ⁻¹ ionomer	Ω
E/8.9AA-0.80K	2.22	1×10^7
E/8.9AA-0.60K	1.67	2×10^{12}
E/8.9AA-0.40K	1.11	$> 1 \times 10^{14}$
E/6.4AA-0.80K	1.67	1×10^7
E/6.4AA-0.60K	1.25	8×10^{13}
E/6.4AA-0.40K	0.83	$> 1 \times 10^{14}$

^a Measured at 296 K and 60% RH.

E/6.4AA-0.80 K and E/8.9AA-0.80 K seemed to already reach a lowest value of $1 \times 10^7 \Omega$ due to the balance between the increase of the number of charged carriers and the reduction of the mobility of charged carriers. Therefore, it is natural that further increase of AA content above 6.4 mol% should not lower surface resistivity if the degree of neutralization is the same. Regarding the neutralization effect on surface resistivity, metal cations in highly neutralized ionomers would be more subject to being hydrated and therefore, become more effective in lowering σ_a because such metal cations have more apparent unoccupied-coordination sites.

The formation of water-coordinated metal cations is considered to be an origin of the conductivity of ethylene ionomers. Therefore, it is easily speculated that ionic conduction would be affected by a moisture level in atmosphere. Figure 3 shows the dependence of ρ_s of E/7.5MAA-0.71 K upon relative humidities. This ionomer maintained low values of ρ_s above $\sim 30\%$ relative humidity, but ρ_s rapidly increased along with further reduction of the relative humidity. The results are reasonable because ethylene ionomers are essentially an insulator in the dry state.^{1,5} Takeoka *et al.* recently studied changes of ionic conduction behavior of the K salts of EMAA by introducing poly(oxyethylene) (POE), and

Figure 3. Dependence of surface resistivity of E/7.5MAA-0.71K upon relative humidities.

found that their ionic conductivity drastically changed from an insulator to an ion-conductor from the POE content of ~ 7 wt%.¹⁵ They attributed the increase of ionic conduction to an improved movement of ions among ionic clusters that are swollen by the POE incorporation. We also found that the introduction of a very small amount of POE into the K salts of EMAA, carried out by an esterification reaction, significantly lowered ρ_s values, especially taken at lower sides of the relative humidity.¹⁶ These findings will be useful when anti-electrostatic ionomers are required to be used at very low humidities.

Surface Resistivity of High- and Low-Acid Ionomer Mixtures

We have uncovered that the K ionomers with anti-electrostaticity tend to absorb a large amount of moisture, and as explained in the Introduction, evaporation of water from ionomers sometimes causes a problem during the melt processing. To cope with this problem, we examined the possibility of reducing the magnitude of moisture absorption by mixing ionomers of different acid levels. For this study, copolymers with 7.5–12.2 mol% MAA and 1.3–5.4 mol% MAA were dry blended at an indicated ratio, and then neutralized with potassium cation. The results are shown in

Table III. Surface resistivity of high- and low-acid ionomer mixtures

Copolymer mixture	Neutralization	Cation content	Surface resist. ^a	Moisture uptake
w/w	mol%	mol kg ⁻¹	Ω	wt%
E/7.5MAA/E/1.3MAA = 50/50	83	1.16	1×10^7	4.2
E/7.5MAA/E/1.3MAA = 50/50	62	0.87	2×10^{11}	2.8
E/7.5MAA/E/1.3MAA = 40/60	78	0.94	2×10^7	3.4
E/7.5MAA/E/1.3MAA = 30/70	70	0.72	2×10^{10}	2.2
E/7.5MAA/E/1.3MAA = 20/80	58	0.49	$> 1 \times 10^{12}$	0.57
E/12.2MAA/E/1.3MAA = 40/60	56	0.94	2×10^{11}	0.53
E/12.2MAA/E/3.5MAA = 40/60	44	0.94	$> 1 \times 10^{12}$	0.36
E/12.2MAA/E/5.4MAA = 40/60	38	0.94	$> 1 \times 10^{12}$	0.38

^a Measured at 296 K and 60% RH. **Figure 4.** Plots of (○) surface resistivity and (●) moisture uptake of the K salts of high- and low-acid EMAA mixtures. **Figure 5.** Schematic figure of surface resistivity and moisture uptake comparing the results from the mixed (—) and straight (---) ionomers.

Figure 4, and the data are summarized in Table III. Interestingly, a downturn in the ρ_s plots shifted to a lower cation content, and the moisture uptake was significantly reduced compared with those observed for the straight ionomers. To make it easier to understand the difference between the straight (Figure 2) and mixed (Figure 4) ionomers, a schematic figure is shown in Figure 5. Obviously, plots of the moisture uptake of both the straight and mixed ionomers have roughly the same relationship with the cation content. This indicates that the amount of water absorbed should be closely related to the amount of potassium cation present. On the contrary, a downturn in the ρ_s plots of the mixed ionomers is seen at the cation

content of $\sim 0.75 \text{ mol kg}^{-1}$ polymer, which is only $\sim 60\%$ of that observed for the straight ionomers. This change is remarkable since it allows to reduce a minimum amount of the moisture uptake needed to obtain an anti-electrostatic ionomer from 4–5 wt% to less than 2 wt%. Such a small level of the moisture uptake is thought to be practically acceptable because some of the mixed ionomers with anti-electrostaticity were melt-processed into films and sheets without any difficulty in our laboratory. From the fact that a plaque of most of the mixed ionomers was less transparent than their pure components, we speculate that the mixed ionomers should form individual continuous layers due to the difference in the

polarity and as far as the high-acid layer provides a pathway for the hydrated cations, they should become anti-electrostatic. We attempted a microscopic analysis, but no clear evidence for the phase separation was obtained. Perhaps, their chemical structure is too close to be distinguished.

Surface Resistivity of Blends of Ionomer with Thermoplastics

In order to determine the suitability of using ionomers as anti-electrostatic additives, blends of 10 wt% of a potassium ionomer, E/9.4AA-0.80 K, with ABS, PA-6, PMMA, PS, LDPE, PBT, PET, and PP were prepared and their ρ_s was examined. The results are tabulated in Table IV. It is obvious that the addition of E/9.4AA-0.80 K remarkably reduced ρ_s of ABS, PA-6, PMMA, and PS. However, the addition of 10 wt% of E/9.4AA-0.80 K was insufficient to reduce ρ_s of LDPE, PBT, PET, and PP. The difference in the efficiency among those thermoplastics probably results from a different state of the ionomer component in the matrix of the mixtures. E/9.4AA-0.80K is certainly immiscible with the thermoplastics employed not only because they are considered to be hydrophobic, but also because a plaque of the binary mixtures is completely opaque except the blend with PMMA. In the case of the former blends, E/9.4AA-0.80 K might

possibly condense near the surface of the sheets when the blends are in a molten state. In the case of the latter blends, the ionomer might rather equally be dispersed over the sheets. Thus, the distribution of the ionomer phase is probably dependent upon the type of the thermoplastics, but this difference can not be explained only by the solubility parameter difference because the solubility parameter of all the thermoplastics employed lies almost in the same range while that of EAA ionomer is much larger.¹⁷ Perhaps, (a) local interactions between the potassium cations and ether oxygen atoms in PET and PBT and (b) the resemblance of the backbones of the ionomer with LDPE and PP may contribute to more random distribution of the ionomer phase. It should be mentioned that the blend of E/9.4AA-0.80 K and PMMA is as transparent as PMMA, but the ρ_s results indicate that they are less miscible. Microscopic and optical measurements we are currently working on will hopefully furnish more information on why this blend is highly transparent.

In order to examine the effect of sample preparation methods on ρ_s of the binary mixtures, ABS was melt blended with 5, 7.5, and 10 wt% of E/9.4AA-0.80 K and 2-mm-thick sheets of each blend were prepared by compression molding and injection molding.

Table IV. Surface resistivity of thermoplastics and their blends with E/9.4AA-0.80K

Thermoplastic	Surface resistivity/ Ω^a	
	Pure component	Blend
ABS	$> 1 \times 10^{14}$	2×10^{10}
PA-6	2×10^{13}	3×10^{11}
PMMA	$> 1 \times 10^{14}$	3×10^{12}
PS	$> 1 \times 10^{14}$	8×10^9
LDPE	$> 1 \times 10^{14}$	$> 1 \times 10^{14}$
PBT	$> 1 \times 10^{14}$	$> 1 \times 10^{14}$
PET	$> 1 \times 10^{14}$	$> 1 \times 10^{14}$
PP	$> 1 \times 10^{14}$	$> 1 \times 10^{14}$

^a Measured at 296 K and 60% RH.

Figure 6. Dependence of surface resistivity of the blends of ABS with E/9.4AA-0.80K upon preparation methods for the measurement samples: (○) compression molding and (●) injection molding.

Data points of ρ_s taken at 296 K and 60% RH are plotted in Figure 6. It is interesting that ρ_s values obtained from the injection-molded sheets are always lower than that obtained from the compression-molded sheets by 2–4 order of the magnitude. The results may imply that a high-rate flow of the melt polymer occurring during the injection molding facilitates the orientation of the ionomer component, which might form a needle-like ionomer phase. On the contrary, the compression molding does not have such an orientation effect. Thus, the results again indicate that the morphology of the polymer mixtures containing an ionomer significantly influences ionic conduction at the surface of the mixtures.

CONCLUSION

The effect of the type of metal cation, acid content, the degree of neutralization, and humidity condition on the anti-electrostatic properties of ethylene ionomers were systematically studied. The method of mixing high- and low-acid ionomers was found to be effective in reducing the magnitude of moisture absorption while maintaining the anti-electrostaticity. This study also revealed a practical use of ethylene ionomers as anti-electrostatic additives for a wide variety of thermoplastics.

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