# Ionomeric Polyblends of Zinc Salts of Maleated EPDM Rubber and Poly(ethylene-*co*-acrylic acid). I. Effect of Blend Ratio

#### PRINCE ANTONY, S. K. DE

Rubber Technology Centre, Indian Institute of Technology, Kharagpur 721 302, India

Received 24 October 1997; accepted 4 June 1998

ABSTRACT: Ionomeric polyblends based on zinc salt of maleated EPDM rubber, abbreviated as Zn-mEPDM and zinc salt of poly(ethylene-*co*-acrylic acid), abbreviated as Zn-PEA in the compositions of 90/10, 80/20, 70/30, 60/40, and 50/50, parts by weight, behave as ionic thermoplastic elastomers. The ionomeric polyblends show synergism in tensile strength, tear strength, and hardness, which is believed to be due to the formation of intermolecular ionic crosslinks, facilitating compatibilization in the blends. The ionomeric polyblend exhibits higher physical properties than the corresponding nonionomeric polyblend. Dynamic mechanical thermal analyses show a high temperature transition due to the presence of a rigid phase arising out of the restricted mobility regions of the polymer chains adjacent to the ionic aggregates. The reprocessability studies reveal that the ionomeric polyblend can be reprocessed. © 1999 John Wiley & Sons, Inc. J Appl Polym Sci 71: 1247–1256, 1999

Key words: ionomeric polyblends; zinc salt; EPDM; thermoplastic elastomers

# **INTRODUCTION**

Thermoplastic elastomers can be prepared by blending a rubber with a thermoplastic in the right proportions.<sup>1-3</sup> The major problem in polymer blending is the lack of compatibility between the polymers to be blended. The mechanical behavior of the polyblends is dependent on the adhesion at the interface for efficient transfer of stress between the component phases.<sup>4</sup> This is governed by the magnitude of interfacial tension between the components in the blends. The interfacial agents are capable of decreasing the interfacial tension, thereby promoting the compatibility.<sup>5,6</sup> These interfacial agents include hydrogen bonding, charge transfer complexes, ion-dipole interactions, and ion-ion interactions.<sup>7,8</sup> The presence of ionic groups in the polymers to be blended enhance the compatibility via intermolecular ionic interactions that assist in compatibilization.<sup>9-11</sup>There are several reports about ion-dipole interactions in the blends.<sup>12-19</sup> Recently, De and coworkers have reported studies on thermoplastic elastomers from the ionomeric polyblends.<sup>20-22</sup>.

The present article reports the results of studies on the development of an ionic thermoplastic elastomer from ionomeric polyblends based on zinc oxide neutralized maleated EPDM rubber, abbreviated as Zn-mEPDM, and zinc oxide neutralized poly(ethylene-co-acrylic acid), abbreviated as Zn-PEA.

## **EXPERIMENTAL**

Details of the materials used are given in Table I.

Correspondence to: S. K. De.

Contract grant sponsor: University Grants Commission, New Delhi.

Journal of Applied Polymer Science, Vol. 71, 1247-1256 (1999)

<sup>© 1999</sup> John Wiley & Sons, Inc. CCC 0021-8995/99/081247-10

| Table I Details of Materials Oscu | Table I | Details | of Materials | Used |
|-----------------------------------|---------|---------|--------------|------|
|-----------------------------------|---------|---------|--------------|------|

| Materials   | Properties  | Source  |
|---|---|---|
| Poly(ethylene-co-acrylic acid), abbreviated as<br>PEA (trade name, Polybond 1009) | Acrylic acid, 6%; $M_w = 97,000$ ;<br>Specific gravity, 0.95;<br>Melt flow rate at 190°C, 6 g/10 min  | Uniroyal<br>Chemical Co.,<br>Naugatuck,<br>U.S.A. |
| Maleated EPDM, abbreviated as mEPDM (trade name, Royaltuf 465)                    | Ethylene content, 55% Specific gravity,<br>0.89 Maleic acid/maleic anhydride<br>content, 1% ML <sub>1+4</sub><br>at 125°C, 60 Molecular weight,<br>$M_{w} = 3.99 \times 10^{5}, M_{n} = 1.16 \times 10^{5}$ | -do-  |
| Zinc oxide  | Rubber grade, Specific gravity, 5.6   | E.Merck Ltd.,<br>Mumbai, India                    |
| Stearic acid  | Rubber grade, Melting point, 76°C   | Obtained locally                                  |

# Preparation of Ionomeric Polyblends of mEPDM and PEA

Formulations used for the blend preparation are given in Table II. Ionomeric polyblends based on mEPDM and PEA were prepared in a Brabender Plasticorder, model PLE-330, at 170°C and at a rotor speed of 60 rpm. First, PEA was allowed to melt for 2 min. Then mEPDM was added and mixed for 2 min. Finally, stearic acid and zinc oxide were added and mixed for another 2 min. Preliminary studies show that 20 phr of zinc oxide was needed for complete neutralization of PEA, and 1 phr of stearic acid was found to increase the rate and extent of the neutralization reaction. Stearic acid reacts with zinc oxide and produce water molecules, which hydrolyse the maleic anhydride groups in the mEPDM to the corresponding acid groups.<sup>23</sup> The resultant zinc stearate may also enhance the solubility of zinc oxide in the polymer matrix. After mixing, the hot material was sheeted out in a two-roll mill. The blends were then molded at 170°C for 20 min in an electrically heated hydraulic press at a pressure of 5 MPa. After molding was over, the blends were cooled to room temperature by the circulation of cold water through the platens.

#### **Measurement of Physical Properties**

The stress-strain properties were measured with dumbbell samples according to ASTM D412 (1987) in a Zwick Universal Testing machine (UTM), model 1445, at a crosshead speed of 500 mm/min. Tear strength was measured in a Zwick UTM, model 1445, using 90° nick-cut crescent samples according to ASTM D624 (1986). The hardness was determined as per ASTM D2240 (1986), and expressed in Shore A units. The tension set at 100% extension was determined as per ASTM D412 (1987).

#### **Dynamic Mechanical Thermal Analyses**

Dynamic mechanical thermal analyses were carried out in a Dynamic Mechanical Thermal analyser (DMTA No. MK-II, Polymer Laboratory, UK). The testing was performed in bending mode with a frequency of 3 Hz over a temperature

| Ingredient   | Blend Number |    |    |    |    |    |     |    |    |  |
|--------------|--------------|----|----|----|----|----|-----|----|----|--|
|              | M0           | M1 | M2 | M3 | M4 | M5 | M6  | M7 | M8 |  |
| mEPDM        | 100          | 90 | 80 | 70 | 60 | 50 | 0   | 60 | 60 |  |
| PEA          | 0            | 10 | 20 | 30 | 40 | 50 | 100 | 40 | 40 |  |
| Zinc oxide   | 20           | 20 | 20 | 20 | 20 | 20 | 20  | 0  | 20 |  |
| Stearic acid | 1            | 1  | 1  | 1  | 1  | 1  | 1   | 0  | 0  |  |

Table IIFormulations of the Blends

|                                  |      | Blend Number |      |      |      |      |      |      |      |
|----------------------------------|------|--------------|------|------|------|------|------|------|------|
| Properties                       | M0   | M1           | M2   | M3   | M4   | M5   | M6   | M7   | M8   |
| Modulus at 100%                  |      |              |      |      |      |      |      |      |      |
| elongation, MPa                  | 1.2  | 2.8          | 3.5  | 5.4  | 6.6  | 8.7  |      | 4.6  | 5.0  |
| Modulus at 200%                  |      |              |      |      |      |      |      |      |      |
| elongation, MPa                  | 1.7  | 4.2          | 4.9  | 6.9  | 7.7  | 9.6  |      | 4.7  | 5.4  |
| Modulus at 300%                  |      |              |      |      |      |      |      |      |      |
| elongation, MPa                  | 2.4  | 5.4          | 6.1  | 8.0  | 8.6  | 10.5 |      | 4.8  | 5.7  |
| Tensile strength, MPa            | 5.6  | 7.6          | 9.3  | 10.9 | 12.3 | 13.1 | 16.2 | 5.1  | 6.0  |
| Elongation at break, %           | 636  | 535          | 628  | 610  | 608  | 540  | 24   | 455  | 488  |
| Tear strength, kNm <sup>-1</sup> | 21.2 | 41.6         | 60.4 | 72.6 | 83.7 | 96.5 | 65.4 | 53.9 | 61.6 |
| Hardness, Shore A                | 54   | 60           | 71   | 77   | 84   | 90   | 90   | 79   | 82   |
| Tension set at 100%              |      |              |      |      |      |      |      |      |      |
| elongation, %                    | 5    | 5            | 10   | 16   | 20   | 38   | —    | 50   | 38   |

#### Table III Physical Properties at 25°C

range of -120 to +150 °C, and at a heating rate of 2 °C/min.

#### Infrared Spectroscopic Studies

Infrared spectroscopic studies on the compression molded thin films of the samples were carried out using Perkin-Elmer 843 spectrophotometer with a resolution of  $3.2 \text{ cm}^{-1}$ .

#### **X-ray Studies**

X-ray studies of the samples were performed with Philips X-ray diffractometer (type PW1840) using a nickel filtered CuK<sub> $\alpha$ </sub> radiation from Philips X-ray generator (type PW1729). Accelerating voltage and electric current were 40 kV and 20 mA, respectively.

# **Scanning Electron Microscopic Studies**

Scanning electron micrographs of the cryogenically fractured blends were taken with Scanning Electron Microscope (Hitachi, model S-415A, Japan). Accelerating voltage was 15 kV. The magnification of the each sample was  $\times 500$ .

#### **Reprocessability Studies**

The reprocessability studies of the 60/40 ZnmEPDM/Zn-PEA blend was studied by extruding the samples through a Monsanto Processability Tester (MPT) at 190°C, using a die of L/D ratio 30 at a shear rate of 122.9 s<sup>-1</sup>. The extrudate was reextruded under similar conditions and the process was repeated for three consecutive cycles. The preheat time for the sample before each extrution was 10 min. The tensile strength of the extrudate from each cycle was measured after a resting period of 24 h.

# **RESULTS AND DISCUSSION**

# **Physical Properties**

The physical properties of the neat ionomers and the ionomeric polyblends are summarized in Table III. The stress-strain properties of the neat ionomers and the ionomeric polyblends are shown in Figure 1. Figure 2 shows the variation of physical properties with blend composition. It is interesting to note that the ionomeric polyblends exert synergism in tensile strength, tear strength, and hardness in the sense that the observed experimental values are higher than that predicted by the additivity rule. The reason for the synergism in properties is believed to be due to the enhanced compatibility via formation of interfacial ionic interactions in the blends. Synergism in properties is reported to be observed in the case of compatible blends.<sup>4</sup> Expectedly, the modulus and tension set increase with increase in PEA content in the blend, and the ionomeric polyblend exhibits a high elongation at break.

It is also interesting to compare the physical properties of the ionomeric polyblend (blend M4) with the corresponding nonionomeric polyblend (blend M7). As expected, blend M4 shows higher physical properties than blend M7. The improved



**Figure 1** Stress-strain plots of Zn-mEPDM (- - -); Zn-PEA (-); blend M1  $(- \cdot \cdot -)$ ; blend M3 (- -), and blend M5 (-x-).

physical properties of blend M4 is the result of formation of intermolecular ionic network structure, which decreases the interfacial energy and enhances the adhesion at the interface, thereby promoting the compatibility in the blend. Blend M7 shows higher tension set than blend M4. This is believed to be the due to the fact that the ionic aggregates present in the ionomeric polyblend act as physical crosslinks, and hence, the decreases in set properties. The role of stearic acid is evident from the physical properties of blend M4 and blend M8. Blend M4, which contains stearic acid, shows higher physical properties than blend M8, blend without stearic acid.

#### **Dynamic Mechanical Thermal Analyses**

Figure 3 shows the plots of tan  $\delta$  vs. temperature of neat ionomers and the ionomeric polyblends. The results of dynamic mechanical thermal analyses are summarized in Table IV. Zn-PEA shows two transitions, one at  $-97.5^{\circ}$ C, which is due to the glass-rubber transition abbreviated as  $T_{g1}$ , and a high temperature transition at 68.5°C, which is presumably due to the occurrence of a rigid phase arising out of the ionic aggregates.<sup>24,25</sup> The temperature corresponding to the high temperature transition is abbreviated as  $T_i$ . The transition at  $T_i$  is suppressed by the gradual raise of tan  $\delta$  due to the melting of the cyrstallites in the Zn-PEA, at 120°C. Zn-mEPDM shows a glass-rubber transition at  $-31.0^{\circ}$ C, abbreviated as  $T_{g^2}$  and a weak diffuse high-temperature transition at 44°C ( $T_i$ ). The blends exhibit two lowtemperature transitions corresponding to the  $T_{g^s}$ of the neat ionomers. This suggests that the blends are immiscible at all compositions. There occurs insignificant changes in the  $T_g$ s of the neat ionomers in the blends. The blends register a weak high-temperature transition. It has been postulated that below a certain ion content, small ionic aggregates behave as crosslinks and dominate the physical property behavior.<sup>26</sup> At higher



**Figure 2** Variation of (a) tensile strength, (b) tear strength, and (c) hardness with blend composition,  $\triangle$ , observed values at 25°C; —, additivity line.



**Figure 3** Plots of tan  $\delta$  vs. temperature of Zn-mEPDM (- - -); Zn-PEA (--); blend M1 (- · · -); blend M3 (-~-), and blend M5 (-x-).

ion concentration, larger ionic aggregates cause immobility of the chain segments in their neighborhood and are responsible for the phase separation in the ionomer.<sup>24</sup> The magnitude of tan  $\delta$  at  $T_i$  in the blends is found to increase with increase in PEA content in the blend. The values of tan  $\delta$  at  $T_i$  of the blends lie inbetween that of the neat ionomers. The transition around 120°C is possibly due to the melting of the crystalline polyethylene block. The tan  $\delta$  at  $T_{g2}$  of the blend decreases with increase in PEA content in the blend. This is attributed to the decrease in amorphous ZnmEPDM phase in the blend as well as due to the stiffening arising out of the intermolecular ionic interactions.

The plots of log E' vs. temperature of the neat ionomers and the ionomeric polyblends are shown in Figure 4. It is apparent that the melting point



**Figure 4** Plots of log E' vs. temperature for Zn-mEPDM (- - -), Zn-PEA (--), blend M1 (- · · -), blend M3 (-~-), and blend M5 (-x-).

of Zn-PEA is in the neighborhood of 120°C and below this temperature, it shows a relatively high modulus due to its high crystallinity. Zn-mEPDM shows a rubbery plateau due to physical crosslinks arising out of the ionic aggregates. It is also noted that increase in PEA content in the blend markedly increases the modulus, presumably due to the increase in crystallinity in the blend. Figure 5 shows the variation of  $\log E'$  vs. blend composition at 30, 70, and 100°C. It is interesting to note that the ionomeric polyblends show synergism in storage modulus. However, the synergestic effect in modulus decreases at high temperature. This indicates the existence of thermally labile ionic crosslinks in the blend. At ambient temperatures, the ionic domains play the role of reinforcing filler and increases the modulus. However, at high temperature the disruption of ionic bonds occur and the modulus decreases.<sup>27</sup>

| Blend<br>Number | $\begin{array}{c} \text{Transition 1} \\ (T_{g_1}),  ^{\circ}\text{C} \end{array}$ | Tan $\delta$ at $(T_{g_1}), \ ^{\circ}C$ | $\begin{array}{c} \text{Transition 2} \\ (T_{g_2}), \ ^{\circ}\text{C} \end{array}$ | Tan $\delta$ at $(T_{g_2})$ , °C | Transition 3 $(T_i)$ , °C | Tan $\delta$ at $(T_i)$ , °C |
|-----------------|--|--|---|----------------------------------|---------------------------|------------------------------|
| <b>M</b> 0      | -97.0  | 0.049                                    | -31.0   | 1.280                            | 44.0                      | 0.113                        |
| $\mathbf{M1}$   | -97.0  | 0.050                                    | -31.0   | 0.945                            | 53.0                      | 0.148                        |
| M2              | -96.3  | 0.050                                    | -32.0   | 0.635                            | 57.0                      | 0.167                        |
| M3              | -97.0  | 0.042                                    | -32.0   | 0.472                            | 58.0                      | 0.182                        |
| M4              | -96.0  | 0.042                                    | -32.0   | 0.320                            | 60.0                      | 0.204                        |
| M5              | -96.5  | 0.042                                    | -33.0   | 0.197                            | 59.0                      | 0.217                        |
| M6              | -97.5  | 0.050                                    | _   | _                                | 65.5                      | 0.225                        |
| M7              | -96.0  | 0.050                                    | -31.5   | 0.345                            |                           | _                            |

Table IV Results of Dynamic Mechanical Thermal Analyses



**Figure 5** Variation of  $\log E'$  at (a) 30°C, (b) 70°C, and (c) 100°C with blend composition,  $\triangle$ , observed values —, additivity line.

Figure 6 shows the plots of tan  $\delta$  and log E' vs. temperature of ionomeric polyblend (blend M4) and the corresponding nonionomeric polyblend (blend M7). It is seen that the tan  $\delta$  at T<sub>g2</sub> of blend M4 is less than that of blend M7. This may be due to the stiffness arising out of the ionic interactions in blend M4. It is also interesting to compare the tan  $\delta$  values at the high temperature region. Blend M4 shows a weak and broad transition at 60°C, in addition to the melting peak around 120°C, due to the presence of rigid ionic phase, whereas blend M7 does not exhibit any high temperature transition. While comparing the  $\log E'$  of the two blends, it can be seen that modulus of blend M4 is slightly higher than that of blend M7. This is again attributed to the effect of ionic linkages present in the blend M4.

# Infrared Spectroscopic Studies

Infrared spectra of the Zn-PEA, Zn-mEPDM, and the Zn-mEPDM/Zn-PEA 80/20 and 60/40 ionomeric polyblends are shown in Figure 7. The spectrum of Zn-PEA shows a weak band at 1714 cm<sup>-1</sup> due to the presence of hydrogen bonded carboxylic acid pairs.<sup>28</sup> A broad band with a peak at 1546 cm<sup>-1</sup> denotes the asymmetric metal carboxylate stretching.<sup>28,29</sup> The strong and intense band at 1464 cm<sup>-1</sup> corresponds to the  $-CH_2$ - bending, and a weak band at 1363 cm<sup>-1</sup> indicates  $-CH_2$ -wagging.<sup>28,30</sup> The spectrum of Zn-mEPDM also shows a broad band centered at 1560  $\text{cm}^{-1}$  in the asymmetric carboxylate stretching region (1650- $1500 \text{ cm}^{-1}$ ), indicating the formation of ionomer. The intensity of the asymmetric carboxylate stretching band of Zn-mEPDM is lower as compared to that of Zn-PEA. This is due to the higher concentration of zinc carboxylate ions in Zn-PEA than that in Zn-mEPDM. A sharp band observed at 1376 cm<sup>-1</sup> is ascribed to the  $-CH_3$  symmetric deformation.<sup>28</sup> Figures 6(c) and (d) represent the infrared spectra of the 80/20 and 60/40 ionomeric polyblends, respectively. The ionomeric polyblends also exhibit a broad band around 1560  $cm^{-1}$  in the asymmetric carboxylate stretching region. This broad band is associated with the



**Figure 6** Plots of tan  $\delta$  and log E' vs. temperature for blend M4 (- - - -) and blend M7 (-O-).



Figure 7 Infrared spectra of (a) Zn-PEA, (b) Zn-mEPDM, (c) blend M2, and (d) blend M4 in the range of 1800-1200 cm<sup>-1</sup>.

coupled asymmetric carboxylate vibration of zinc carboxylate ions present in the neat ionomers.

The existence of a broad band is due to the overlapping of different bands, and such a band can be separated into different bands by using derivative spectroscopy.<sup>31</sup> Coleman and coworkers have studied the second derivative spectra of zinc salt of an ethylene–methacrylic acid copolymer in the range of  $1630-1500 \text{ cm}^{-1}$ .<sup>32</sup> Figure 8 shows the second derivative spectra of neat ionomers and the ionomeric polyblends in the asymmetric carboxylate stretching region. It is inter-

esting to note that the broad band in the asymmetric carboxylate stretching region of the neat ionomers and the ionomeric polyblends are composed of four different bands. The splitting of bands is due to the existence of different coordinated structures of zinc cation.<sup>33</sup> The band around 1630 cm<sup>-1</sup> is assigned to the acid–salt complex. A pair of bands around 1564/1541 cm<sup>-1</sup> is believed to be due to the asymmetric octahedral zinc carboxylate stretching, and a band around 1595 cm<sup>-1</sup> accounts for the asymmetric tetrahedral zinc carboxylate stretching.<sup>32</sup> It can also be seen that in the case of ionomeric polyblends the octahedral band at 1536 cm<sup>-1</sup> is more intense than the other bands.

The interaction between the two neat ionomers in the blends was studied by using the difference spectra (Fig. 9). The difference spectra was obtained by subtracting the weighted addition spectra of the neat ionomers from the corresponding blend spectrum. It is known that in the case of



**Figure 8** Second derivative spectra of (a) Zn-PEA, (b) Zn-mEPDM, (c) blend M2, and (d) blend M4 in the range of 1650-1500 cm<sup>-1</sup>.



**Figure 9** Difference spectra obtained by subtracting the sum of the spectra of the neat ionomers from the blend spectra. (a) blend M2, and (b) blend M4 in the range of  $1800-1200 \text{ cm}^{-1}$ .

compatible polyblends, there occurs a marked difference between the summation spectrum and the experimental blend spectrum.<sup>34</sup> Difference spectrum shows a positive band at 1536 cm<sup>-1</sup> in the case of both the blends, but shows a negative band in the range of 1650–1550 cm<sup>-1</sup>. This is believed to be due to the changes in spectral features of the asymmetric carboxylate stretching region due to the mutual interaction of the component ionomers in the blends.

# **X-ray Studies**

Results of X-ray studies are summarized in Table V. It is known that formation of ionomer decreases the percent crystallinity.<sup>26</sup> It is seen that Zn-PEA exhibits lower crystallinity than the nonionic PEA. It is also apparent that the percent crystallinity of the 60/40 Zn-mEPDM/Zn-PEA blend is less than the corresponding nonionomeric polyblend. The percent crystallinity of the ionomeric polyblends increase with increase in PEA content in the blend.

| 1.1    | 1.126 |                   | <u> </u>      |
|--------|-------|-------------------|---------------|
| 1000   |       |                   | 2             |
| 1-4-   | 2012  |                   |               |
| ALC:   |       |                   |               |
|        |       | $\sim 10^{\circ}$ |               |
| 10 Mar |       | Constant.         | $\mathcal{I}$ |
|        |       | al de             |               |
| Sec. 1 |       | 10K 601           | Î.E           |

(b)



(a)

**Figure 10** Scanning electron photomicrographs of (a) blend M4 and (b) blend M7.

# **Scanning Electron Microscopic Studies**

Scanning electron photomicrographs of the fractured surfaces of the 60/40 nonionomeric polyblend (blend M7) and the corresponding ionomeric polyblend (blend M4) are shown in Figure 10. Although incompatibility or macroheterogeneity is evident in blend M7, blend M4 shows com-

|                          |    |    |    | В  | lend Num | lber |    |    |     |
|--------------------------|----|----|----|----|----------|------|----|----|-----|
| Property                 | M0 | M1 | M2 | M3 | M4       | M5   | M6 | M7 | PEA |
| Percent crystallinity, % | 0  | 8  | 12 | 18 | 21       | 28   | 56 | 28 | 61  |

#### Table V Results of X-ray Studies

patibility or homogeneity of the blend components, which is believed to be due to the interfacial ionic interactions, as discussed earlier.

#### **Reprocessability Studies**

Figure 11 shows the variation of apparent viscosity and tensile strength of the extrudate of the 60/40 Zn-mEPDM/Zn-PEA blend with the number of cycles of extrusion. It can be seen that the apparent viscosity of the blend and the tensile strength of the extrudate almost remain unchanged by repeated extrusions, indicating the thermoplastic elastomeric nature of the blend. The constant values of apparent viscosity and tensile strength of the extrudate even after three cycles of extrusion indicate the thermal and shear stabilities of the blend.

A schematic representation of the biphasic structure in the ionomeric polyblends is shown in Figure 12. The hard domains in the ionomeric polyblends consist of crystalline domain due to polyethylene blocks and ionic domain due to zinc carboxylate ions.

# CONCLUSIONS

- 1. Ionomeric polyblends of Zn-mEPDM and Zn-PEA in the ratios of 90/10, 80/20, 70/30, 60/40, and 50/50, parts by weight, behave as ionic thermoplastic elastomers.
- 2. The synergism in properties of the ionomeric polyblends are due to the occurrence of strong interfacial ionic crosslinks, which enhance the compatibility in the blends.
- 3. The ionomeric polyblend exhibits higher



**Figure 11** Variation of apparent viscosity at 190°C and tensile strength of the extrudates at 25°C of blend M4 with extrusion cycle.



Figure 12 Schematic representation of the biphasic structure in the Zn-mEPDM/Zn-PEA ionomeric polyblend.

physical properties than the corresponding nonionomeric polyblend.

- 4. Dynamic mechanical thermal analyses show the biphasic nature of the ionomeric polyblends and occurrence of a high temperature transition due to the relaxation of immobile segments of the polymer chains in the neighborhood of ionic aggregates.
- 5. Scanning electron microscopic studies reveal the enhanced compatibility in the ionomeric polyblend.
- 6. Reprocessability studies reveal the thermoplastic elastomeric nature of the ionomeric polyblend.

The authors gratefully acknowledge Uniroyal Chemical Co., USA, for supplying the materials and also University Grants Commission, New Delhi, for providing the financial support for the present work.

# REFERENCES

- 1. Coran, A. Y.; Patel, R. Rubber Chem Technol 1982, 53, 141.
- De, S. K.; Bhowmick, A. K., Eds.; Thermoplastic Elastomers from Rubber-Plastic Blends; Ellis Horwood: London, 1990.
- 3. Legge, N. R.; Holden, G.; Schroeder, H. E., Eds.; Thermoplastic Elastomers; Hanser: Munich, 1987.
- Paul, D. R.; Barlow, J. W. J Macromol Sci Rev Macromol Chem 1980, C18, 109.
- 5. Xanthos, M. Polym Eng Sci 1988, 28, 1392.
- Gaylord, N. G. J Macromol Sci Chem 1989, A26, 1211.
- Coleman, M. M.; Graf, J. F.; Painter, P. C. Specific Interactions and Miscibility of Polymer Blends; Technomic Publishing Co.: Lancaster, PA, 1991.

- Olabisi, O.; Robeson, L. M.; Shaw, M. T. Polymer– Polymer Miscibility; Academic Press: New York, 1979.
- MacKnight, W. J.; Lunderg, R. D. In Thermoplastic Elastomers; Legge, N. R.; Holden, M. G.; Schroeder, H. E., Eds.; Hanser: Munich, 1987, p. 245.
- Smith, P.; Hara, M.; Eisenberg, A. In Current Topics in Polymer Science; Hanser Publishers: New York, 1987, Vol 2, p. 255.
- Fitzgerald, J. J.; Weiss, R. A. J Macromol Sci Rev Macromol Chem Phys 1988, C28, 99.
- Eisenberg, A.; Smith, P.; Zhou, Z. L. Polym Eng Sci 1982, 22, 455.
- Zhou, Z. L.; Eisenberg, A. J Polym Sci Polym Phys Ed 1983, 21, 591.
- Rutkowska, M.; Eisenberg, A. J Appl Polym Sci 1984, 29, 755.
- Rutkowska, M.; Eisenberg, A. Macromolecules 1984, 17, 821.
- Rutkowska, M.; Eisenberg, J. Appl Polym Sci 1984, 30, 3317.
- 17. Lu, X.; Weiss, R. A. Macromolecules 1992, 25, 6185.
- Molnar, A.; Eisenberg, A. Macromolecules 1992, 25, 5774.
- 19. Lu, X.; Weiss, R. A. Macromolecules 1996, 29, 1216.
- 20. Datta, S. De, P. P.; De, S. K. J Appl Polym Sci 1996; 61, 1839.
- Kurian, T.; Datta, S.; Khastgir, D.; De, P. P.; Tripathy, D. K.; De, S. K.; Peiffer, P. G.; Polymer 1996, 37, 4787.

- Antony, P.; Datta, S.; De, S. K. Paper presented at a meeting of the Rubber Division, ACS, Anaheim, California, May 6–9, 1997.
- Datta, S. De, S. K.; Kontos, E. G.; Wefer, J. M. J Appl Polym Sci 1996, 61, 177.
- 24. Eisenberg, A.; Hird, B.; Moore, R. B. Macromolecules 1990, 23, 4098.
- 25. Hird, B.; Eisenberg, A. Macromolecules 1992, 25, 6466.
- 26. Bazuin, C. G.; Eisenberg, A. Ind Eng Chem Prod Res Dev 1981, 20, 271.
- 27. MacKnight, W. J.; Earnest, T. R. J Polym Sci Macromol Rev 1981, 16, 41.
- Smith, A. L. Applied Infrared Spectroscopy; Wiley Interscience Publication: New York, 1979, p. 287.
- Williams, D. H.; Fleming, I. Spectroscopic Methods in Organic Chemistry; McGraw-Hill: London, 1987, p. 29.
- Coleman, M. M.; Painter, P. C. J Macromol Sci Rev Macromol Chem 1977, C16, 197.
- Henniker, J. C. Infrared Spectroscopy of Industrial Polymers; Academic Press Inc.: London, 1967, p. 120.
- Coleman, M. M.; Lee, J. Y.; Painter, P. C. Macromolecules 1990, 23, 2339.
- Brozoski, B. A.; Coleman, M. M.; Painter, P. C. Macromolecules 1984, 17, 230.
- Coleman, M. M.; Painter, P. C. Appl Spectrosc Rev 1984, 20, 255.