

# Tensile Properties and Morphology of the Dynamically Cured EPDM and PP/HDPE Ternary Blends

CHANG SIK HA, *Department of Polymer Science and Engineering, Pusan National University, Pusan 609-735, Korea* and SUNG CHUL KIM, *Department of Chemical Engineering, Korea Advanced Institute of Science and Technology, Seoul 136-791, Korea*

## Synopsis

The tensile properties and morphology of the polyolefin ternary blends of ethylene-propylene-diene terpolymer (EPDM), polypropylene and high density polyethylene were studied. Blends were prepared in a laboratory internal mixer where EPDM was cured in the presence of PP and HDPE under shear with dicumyl peroxide (DCP). For comparison, blends were also prepared from EPDM which was dynamically cured alone and blended with PP and HDPE later (cure-blend). The effect of DCP concentration, intensity of the shear mixing, and rubber/plastics composition was studied. The tensile strength and modulus increased with increasing DCP concentration in the blends of EPDM-rich compositions but decreased with increasing DCP concentration in blends of PP-rich compositions. In the morphological analysis by scanning electron microscopy (SEM), the small amount of EPDM acted as a compatibilizer to HDPE and PP. It was also revealed that the dynamic curing process could reduce the domain size of the crosslinked EPDM phase. When the EPDM forms the matrix, the phase separation effect becomes dominant between the EPDM matrix and PP or HDPE domain due to the crosslinking in the matrix.

## INTRODUCTION

Recently the rheological properties and crystalline structure of the dynamically cured ethylene-propylene-diene terpolymer (EPDM) and PP/HDPE ternary blends was reported.<sup>1</sup> The blends of crosslinked EPDM and PP/HDPE were prepared in a laboratory internal mixer by the "dynamic curing" method where EPDM was cured under shear with peroxide.

Several works have been published on the rheological and mechanical properties of the dynamically cured EPDM and polyolefin blends,<sup>2-6</sup> but virtually no morphological studies have been reported as yet on the dynamically cured blends.

The objective of this study is to clarify the effect of DCP concentration, the intensity of the shear mixing, and the rubber/plastics composition on the morphology and mechanical properties of the dynamically cured EPDM and PP/HDPE ternary blends.

## EXPERIMENTAL

The polymers used in this study are listed in Table I. The polypropylene (PP), high density polyethylene (HDPE), and ethylene-propylene-diene terpolymer (EPDM) with ethylidene-2-norbornene (ENB) as a termonomer

TABLE I  
Materials

Materials	Characteristics		Source
PP	MFI	6.0	PP4017 (Korea Petrochem.)
	$M_w$	$2.201 \times 10^5$	
	$M_n$	$2.829 \times 10^4$	
HDPE	MFI	0.8	E308 (Korea Petrochem.)
	$M_w$	$1.002 \times 10^5$	
	$M_n$	$1.310 \times 10^4$	
EPDM <sup>a</sup>	$\eta_{inh}$ (dL/g)	1.22	Roy. 521 (Uniroyal)
	IV <sup>b</sup>	15.2	
	PE/PP (by mol %) <sup>c</sup>	52.0/48.0	
DCP	Granule type		Mitsui Chem.

<sup>a</sup>0.5 g/dL xylene solution at 70°C.<sup>b</sup>by ICI titration method.<sup>c</sup>by IR analysis.

were all commercially available grades. The polymers were cured with various amounts of dicumyl peroxide (DCP). Blends were prepared by two different methods, blend-cure process and cure-blend process. The preparation of the blends is described elsewhere.<sup>1</sup> The sample notation is listed and described in Table II.

TABLE II  
Sample Description

Sample Notation	Composition (wt. %)			
	EPDM	PP + HDPE	PP/(PP + HDPE)	HDPE/(PP + HDPE)
PP75PE25	0	100	75	25
PP50PE50	0	100	50	50
PP25PE75	0	100	25	75
RL25P75 <sup>a</sup>	25	75	75	25
RL25S75	25	75	50	50
RL25E75	25	75	25	75
RB(C)25P75 <sup>b</sup>	25	75	75	25
RB(C)25S75	25	75	50	50
RB(C)25E75	25	75	25	75
RL50P50	50	50	75	25
RL50S50	50	50	50	50
RL50E50	50	50	25	75
RB(C)50P50	50	50	75	25
RB(C)50S50	50	50	50	50
RB(C)50E50	50	50	25	75
RL75P25	75	25	75	25
RL75S25	75	25	50	50
RL75E25	75	25	25	75
RB(C)75P25	75	25	75	25
RB(C)75S25	75	25	50	50
RB(C)75E25	75	25	25	75

<sup>a</sup>P denotes PP-rich composition; S denotes same wt % of PP and HDPE compositions; E denotes HDPE-rich composition in the ternary blends.

<sup>b</sup>RL means linear EPDM; RB(C) means blend-cure (RB) and cure-blend (RC).

TABLE III  
Tensile Properties of the EPDM/PP/HDPE Homopolymers and Linear Ternary Blends

Sample notation	Tensile strength (kg/cm <sup>2</sup> )	Elongation at break (%)	Young's modulus (kg/cm <sup>2</sup> )
PP100	285	780	3850
PE100	243	890	3060
EPDM100	4	60	20
RL25P75	168	51.5	2750
RL25S75	140	73.7	2220
RL25E75	97	370.7	1360
RL50P50	57	159.7	1190
RL50S50	57	237.0	660
RL50E50	38	237.7	560
RL75P25	20	121.3	70
RL75S25	19	130.9	75
RL75E25	6	168.9	30

The tensile tests were carried out using an Instron tensile tester (Model 1127) on the samples prepared according to ASTM D638-84. The crosshead speed was 100 mm/min, and the gauge length was 20 mm.

Scanning electron micrographs (SEM) were obtained by JEOL JSM35-CF SEM. Samples were cryogenically fractured in liquid nitrogen and metallized by gold coating prior to the installation in the SEM chamber.

## RESULTS AND DISCUSSION

### Tensile Properties

Tensile properties of the linear ternary blends are given in Table III and Figure 1. The tensile strength and modulus are reduced as the EPDM content increases. The reduction in tensile properties should be expected as the result of a rubbery nature of EPDM.

Table IV and Figure 2 show the effect of DCP concentration on the tensile properties of the dynamically cured EPDM and PP/HDPE ternary blends. It is generally observed that in the PP-rich blend the tensile strength and modulus slightly decrease with increasing DCP concentration due to the peroxide-induced mechanochemical degradation of PP whereas, for the EPDM-rich blends, the tensile strength and modulus increase with increasing DCP concentration due to the chemical crosslinking of EPDM by DCP.

It is also noted, as shown in Table IV and Figure 3, that the elongation at break in the dynamically cured PP-rich blends (for instance, RB25P75 blends) decrease with increasing DCP content and that the values are much lower when compared to those of any other blends. This behavior may also be related to the mechanochemical degradation of PP.

It is also interesting to note that all the EPDM-rich (RB75 designated compositions) blends show maximum elongation at break at intermediate DCP concentration. This may be caused by a number of factors acting independently and simultaneously, including the decreasing crystallinity of PP and HDPE by blending with EPDM, the mechanochemical degradation of

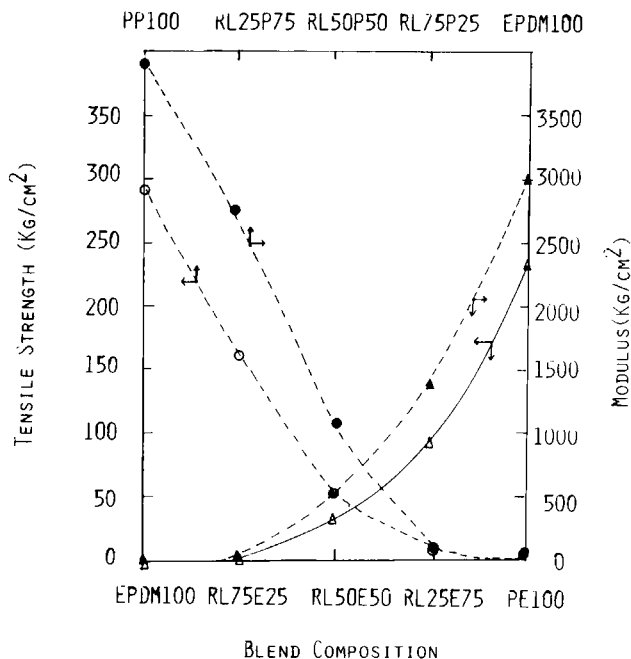


Fig. 1. Tensile strength with blend composition for the linear EPDM/PP/HDPE ternary blends.

PP, and the chemical crosslinking of the EPDM, etc. The results obtained may be a combination of all the factors mentioned above.

Table V shows that the tensile strength and modulus of the dynamically cured EPDM and PP/HDPE ternary blends are not significantly affected by the intensity of the shear mixing or preparative methods over all the composition ranges examined. It must be pointed out, however, that the elongations at break are generally greater when the blends are prepared at 60 rpm than when prepared at 20 rpm for the blend-cure materials except for the RB25-designated samples of 25 wt % of EPDM. The increase in elongation at break with increasing shear intensity is likely to be ascribed to the morphological changes in the blends, even though the accurate interpretation is at the moment not easy.

### Morphology

The morphology of the EPDM/HDPE and PP/HDPE binary blends as well as the linear EPDM/PP/HDPE ternary blends and the dynamically cured EPDM/PP/HDPE blends by scanning electron microscopy (SEM) is analyzed.

#### EPDM/HDPE and PP/HDPE Binary Blends

For PP/HDPE binary blends, as shown in Figure 4, the PP and HDPE are incompatible and their phases are grossly separated. The SEM micrographs show that small HDPE particles of the order of 1–3  $\mu\text{m}$  are dispersed in the continuous matrix of PP for the blend of PP75PE25 composition, but large PP

TABLE IV  
Tensile Properties of the Dynamically Cured EPDM/PP/HDPE Ternary Blends;  
Effect of DCP Concentration (Mixer Speed 60 rpm)

Sample notation	DCP conc (phr)	Tensile strength (kg/cm <sup>2</sup> )	Elongation at break (%)	Young's modulus (kg/cm <sup>2</sup> )
RB25P75	0	168	51.5	2750
	0.33	141	15.3	2660
	0.67	139	14.7	2280
	1.00	131	13.8	1590
	1.33	134	8.4	2140
RB25S75	0	140	73.7	2220
	0.33	125	52.1	1960
	0.67	130	14.4	2110
	1.00	129	13.8	2240
	1.33	128	10.2	2590
RB25E75	0	97	370.7	1360
	0.33	96	255.9	1380
	0.67	100	274.8	1730
	1.00	112	253.3	1980
	1.33	95	279.2	2370
RB50P50	0	57	159.7	1190
	0.33	52	75.5	820
	0.67	63	115.7	750
	1.00	75	233.7	870
	1.33	83	224.7	820
RB50S50	0	57	237.0	660
	0.33	72	240.0	660
	0.67	58	258.1	660
	1.00	66	243.3	840
	1.33	91	315.2	600
RB50E50	0	38	237.7	560
	0.33	50	424.4	570
	0.67	60	380.0	570
	1.00	78	365.5	870
	1.33	70	317.7	460
RB75P25	0	20	121.3	70
	0.33	30	177.1	100
	0.67	47	265.2	150
	1.00	59	169.9	140
	1.33	66	169.9	155
RB75S25	0	19	130.9	75
	0.33	31	188.2	85
	0.67	32	304.4	155
	1.00	73	180.7	170
	1.33	78	184.9	190
RB75E25	0	6	168.9	30
	0.33	19	289.1	65
	0.67	30	250.2	105
	1.00	68	184.0	110
	1.33	63	167.8	70

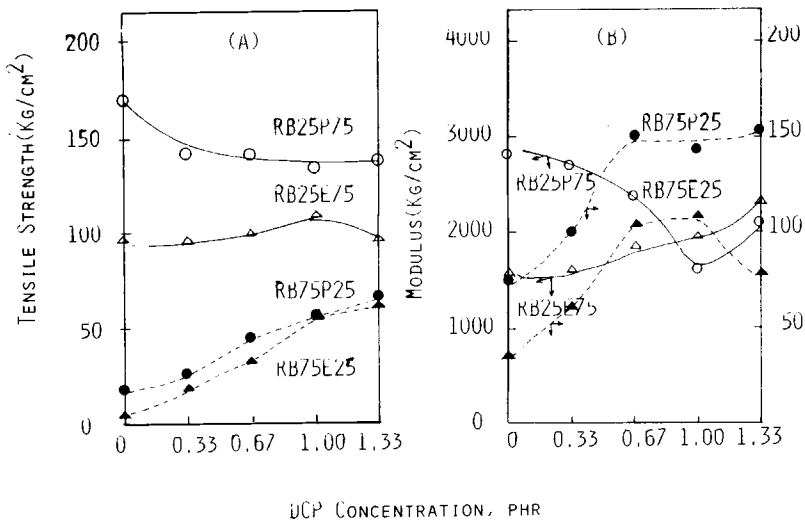


Fig. 2. The effect of DCP concentration on the tensile strength (A) and the modulus (B) for the dynamically cured EPDM and PP/HDPE ternary blends.

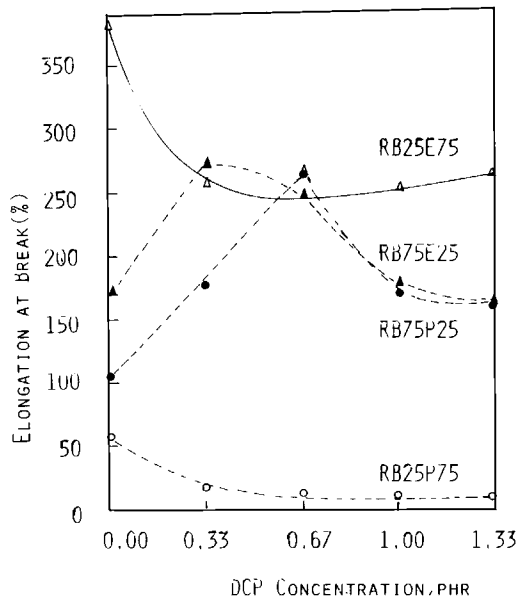


Fig. 3. Elongations at break with DCP concentration for the dynamically cured EPDM and PP/HDPE ternary blends.

domains of 6–10  $\mu\text{m}$  in size are dispersed in the continuous HDPE matrix for the PP25PE75 blend.

It is interesting to note that the blends show two-phase structure over the composition ranges examined and the phase separation between two components is more evident for the HDPE-rich blend than the PP-rich blend.

Careful inspection of the micrograph for the PP50PE50 blend reveals that both HDPE and PP phases are interconnected. Lovinger and Williams,<sup>7</sup> who

TABLE V  
Tensile Properties of the Dynamically Cured EPDM/PP/HDPE Blends;  
Effect of Shear Intensity and Preparative Methods (DCP 0.67 phr)

Sample notation	Mixer rotation (rpm)	Tensile strength (kg/cm <sup>2</sup> )	Elongation at break (%)	Young's modulus (kg/cm <sup>2</sup> )
RB25P75	20	120	21.3	2420
	60	139	14.7	2280
RC25P75	60	139	19.7	2140
RB25S75	20	135	21.7	1660
	60	130	14.4	2110
RC25S75	60	132	18.8	2820
RB25E75	20	100	359.2	1665
	60	100	274.8	1730
RC25E75	60	85	220.2	1890
RB50P50	20	64	68.6	820
	60	63	115.7	750
RC50P50	60	63	133.1	410
RB50S50	20	65	151.6	840
	60	58	258.1	660
RC50S50	60	58	258.1	290
RB50E50	20	66	229.5	380
	60	60	380.0	570
RC50E50	60	55	376.6	280
RB75P25	20	57	194.7	135
	60	47	265.2	150
RC75P25	60	47	265.2	150
RB75S25	20	31	211.8	150
	60	32	304.4	155
RC75S25	60	17	224.4	140
RB75E25	20	21	330.3	140
	60	30	250.2	105
RC75E25	60	30	250.2	105

studied the relationship of tensile properties and morphology of the blend, concluded that the lower elongation at break of the blend might be attributed to the two-phase structure consisting of interconnecting networks of domains of HDPE in a PP matrix.

For the EPDM/HDPE binary blend, it is shown that the EPDM particles of 0.4–0.6  $\mu\text{m}$  in diameter are dispersed in HDPE matrix for PE75EPDM25 blend and HDPE particles of similar size are dispersed in EPDM matrix for PE25EPDM75 blend (Fig. 5).

The SEM micrograph of the PE75EPDM25 blend with higher magnification (Fig. 6) shows that the volume fraction of EPDM in the blend is somewhat larger than that of the initially added amount of EPDM. This result may be due to the semicompatibility of the EPDM and HDPE. Careful inspection of Figure 6 reveals rough fractured surfaces, which indicate good adhesion of EPDM and HDPE.

The different compatibilities or segmental solubilities of the EPDM with PP or HDPE depend on the molecular parameters such as ethylene content, molecular weight, termonomer type and content, stereoblock length of the ethylene and/or propylene segments, etc.<sup>8-14</sup>

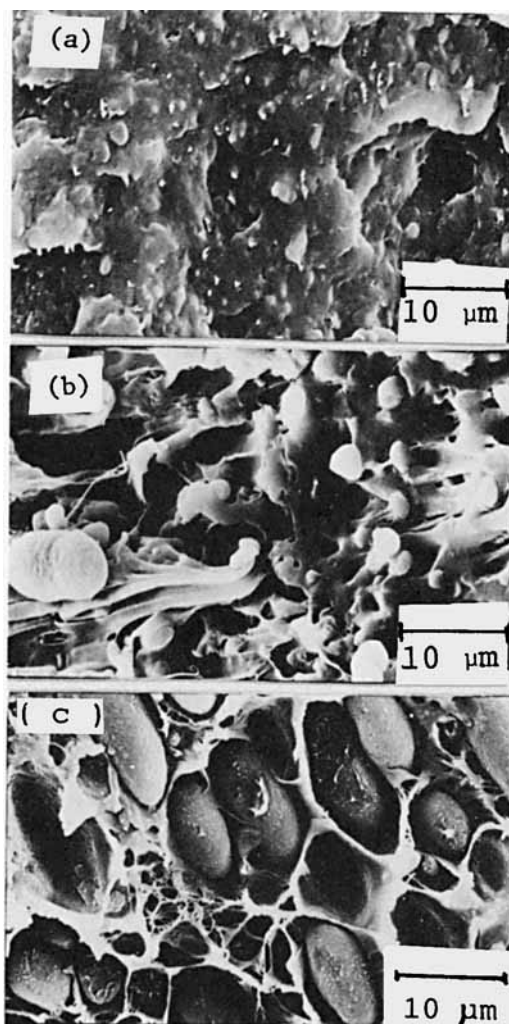


Fig. 4. SEM micrographs of PP/HDPE binary blends: (a) PP75PE25; (b) PP50PE50; (c) PP25PE75.

In this system, the segmental mobilities of EPDM and HDPE seem to be higher than those of EPDM and PP because of slightly higher ethylene units in the EPDM chain.

#### EPDM/PP/HDPE Ternary Blends with 25% EPDM

SEM micrographs of the fractured surfaces of the linear blend of EPDM/PP/HDPE with 25% EPDM (RL25-designated blend) are shown in Figure 7. The addition of 25 wt % of EPDM to the binary HDPE/PP blends drastically changes the overall morphology.<sup>15,16</sup> The blends of RL25P75 show that the EPDM and HDPE are combined to form composite particles dispersed in PP matrix [Fig. 7(a)]. Stehling et al.<sup>17</sup> reported that EPDM interlayer between the HDPE domain and the PP matrix was the possible



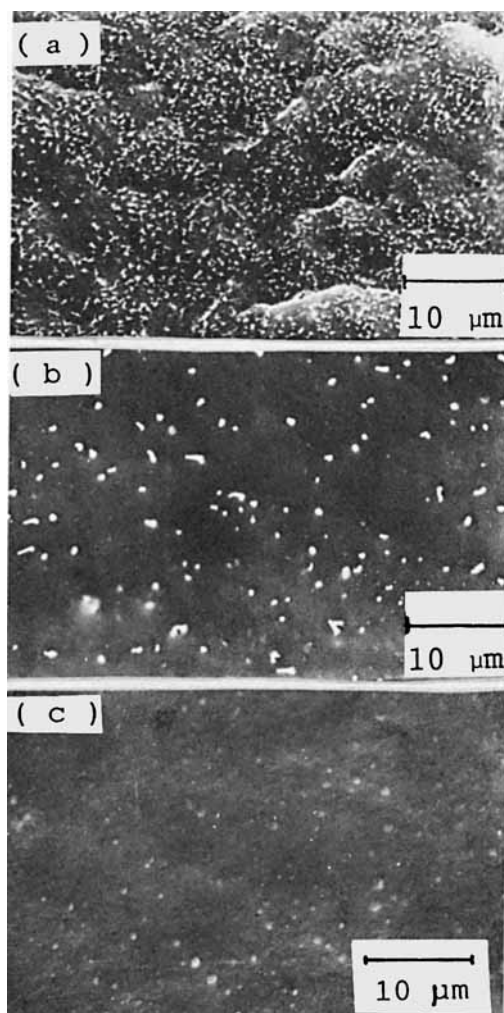


Fig. 5. SEM micrographs of EPDM/HDPE binary blends: (a) PE75EPDM25; (b) PE50EPDM50; (c) PE25EPDM75.



Fig. 6. SEM micrographs of PE75EPDM25 blend; higher magnification ( $\times 15,000$ ).

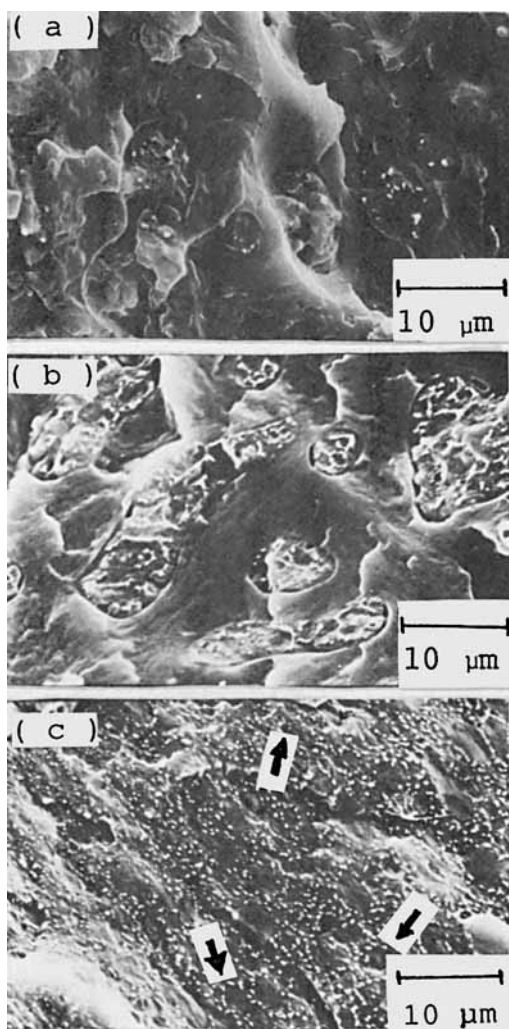


Fig. 7. SEM micrographs of EPDM/PP/HDPE linear ternary blends of 25 wt % EPDM: (a) RL25P75; (b) RL25S75; (c) RL25E75.

morphology from the interfacial energy considerations.<sup>18,19</sup> The RL25E75 blend [Fig. 7(c)] shows very different morphology compared to those of RL25P75 and RL25S75 blends. It is apparent, as indicated by the arrows, that the PP domain of 2–4  $\mu\text{m}$  and EPDM domains of 0.4–0.6  $\mu\text{m}$  in size are distributed separately in the HDPE matrix. Comparison of Figures 4(c) and 7(c) reveals that the domain size of PP phase ranges from 6 to 10  $\mu\text{m}$  in PP25PE75 binary blend and from 2 to 4  $\mu\text{m}$  in RL25E75 ternary blend, which indicates the compatibilizing effect of the EPDM phase.

The dynamically cured PP-rich blends (RB25P75) also show the composite particles of EPDM and HDPE dispersed in the PP matrix (Fig. 8). The composite particles are 3–7  $\mu\text{m}$  in diameter. It is noteworthy that the shape of HDPE particles encapped in EPDM is irregularly deformed, and the surrounding EPDM layer is also irregular in shape. The magnified composite

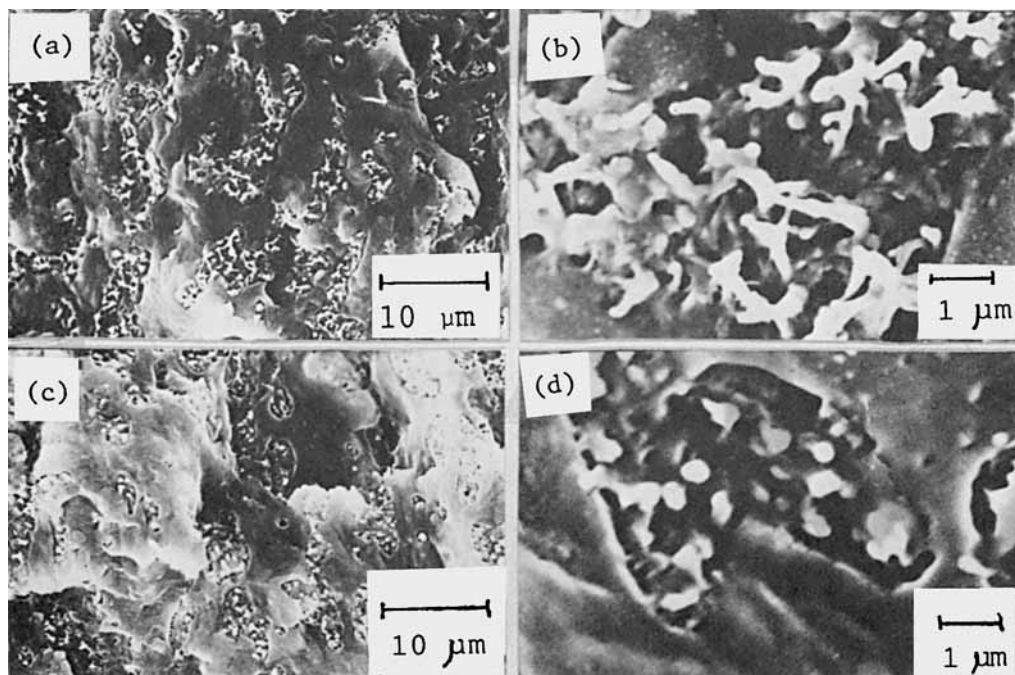


Fig. 8. SEM micrographs of the dynamically cured RB25P75 ternary blends with DCP concentration of 0.67 phr; the effect of the shear intensity. Mixer speed: (a) 20 rpm ( $\times 2600$ ); (b) 20 rpm ( $\times 15,000$ ); (c) 60 rpm ( $\times 2600$ ); (d) 60 rpm ( $\times 15,000$ ).

particle micrograph [Fig. 8(b)] shows intermixed HDPE and EPDM phases within the composite particles. The effect of the shear intensity during the blend-cure process is shown by comparing Figures 8(a) and 8(c). Under high shear, the composite particle size becomes smaller, and the surrounding EPDM layer becomes more continuous. This feature may be due to the poorer compatibility of crosslinked EPDM with HDPE and PP when prepared at lower shear intensity of mixing.

The dynamically cured HDPE-rich blends (RB25E75) show that the PP and EPDM domains are distributed separately in the HDPE matrix, which is similar to the RL25E75 linear ternary blend. [Compare Figs. 7(c) and 9(b).] Figure 9 shows the effect of the shear intensity on the morphology of the HDPE-rich ternary blends. It is clearly shown that very fine dispersions of PP domain are observed for the RB25E75 blend prepared at 60 rpm [Fig. 9(b)] whereas the distinct segregated PP domains of 2–3  $\mu\text{m}$  in size are observed in HDPE matrix for RB25E75 prepared at 20 rpm [Fig. 9(a)].

The effect of the DCP concentration for the RB25P75 and RB25E75 compositions is shown in Figures 10 and 11. For the RB25P75 blends, when DCP content is 1.0 phr, the EPDM domain surrounding the HDPE particle is 3–5  $\mu\text{m}$  in diameter and is dispersed in PP matrix, whereas at DCP content of 0.33 phr the EPDM domain is much larger (about 10  $\mu\text{m}$  in diameter) (Fig. 10). This may be attributed to the fact that the rubber particle size is reduced with crosslinking at high DCP content. Dao<sup>20,21</sup> reported that the rubber particle growth is inhibited and stabilized at high crosslinking density.

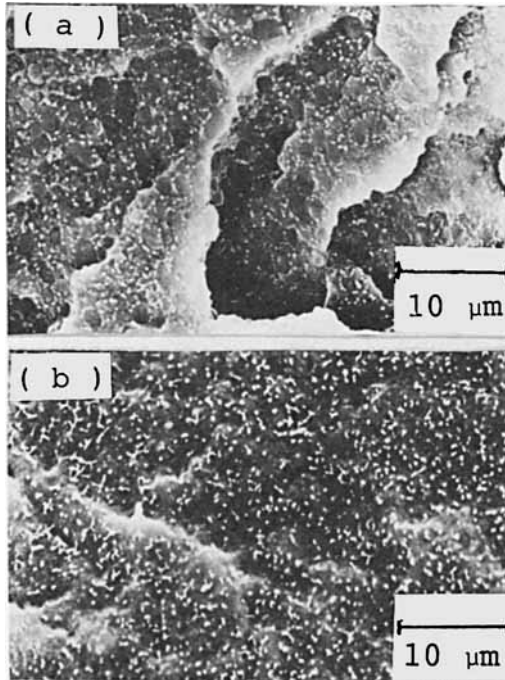


Fig. 9. SEM micrographs of the dynamically cured RB25E75 ternary blends with DCP concentration of 0.67 phr; the effect of the shear intensity. Mixer speed: (a) 20 rpm ( $\times 2600$ ); (b) 60 rpm ( $\times 2600$ ).

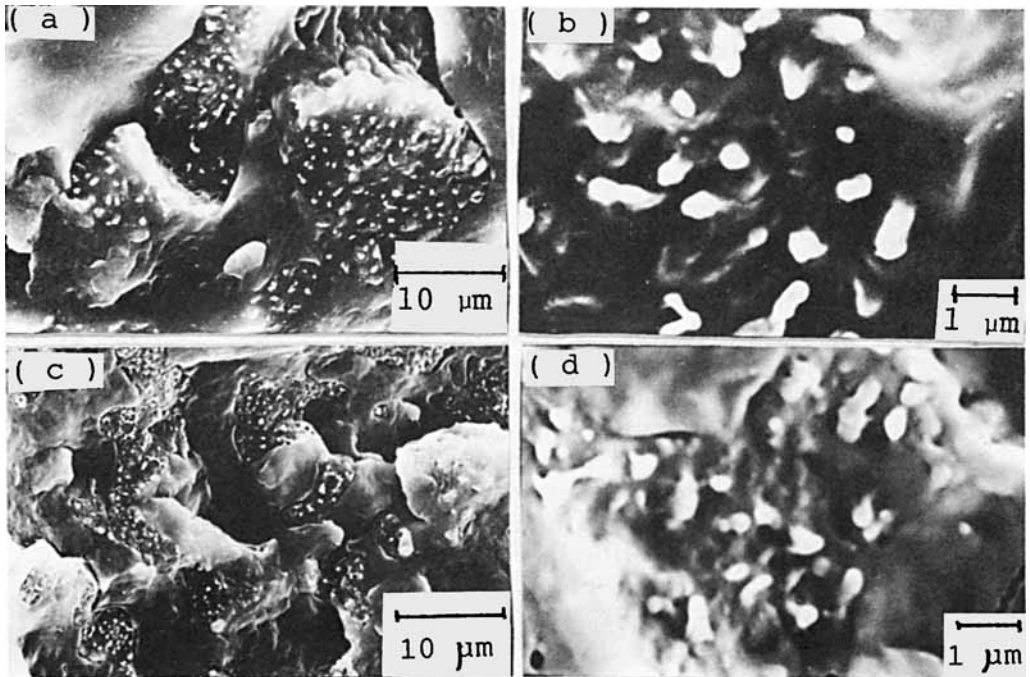


Fig. 10. SEM micrographs of the dynamically cured RB25P75 ternary blends prepared at 60 rpm; the effect of DCP concentration: (a) 0.33 phr ( $\times 2600$ ); (b) 0.33 phr ( $\times 15,000$ ); (c) 1.00 phr ( $\times 2600$ ); (d) 1.00 phr ( $\times 15,000$ ).

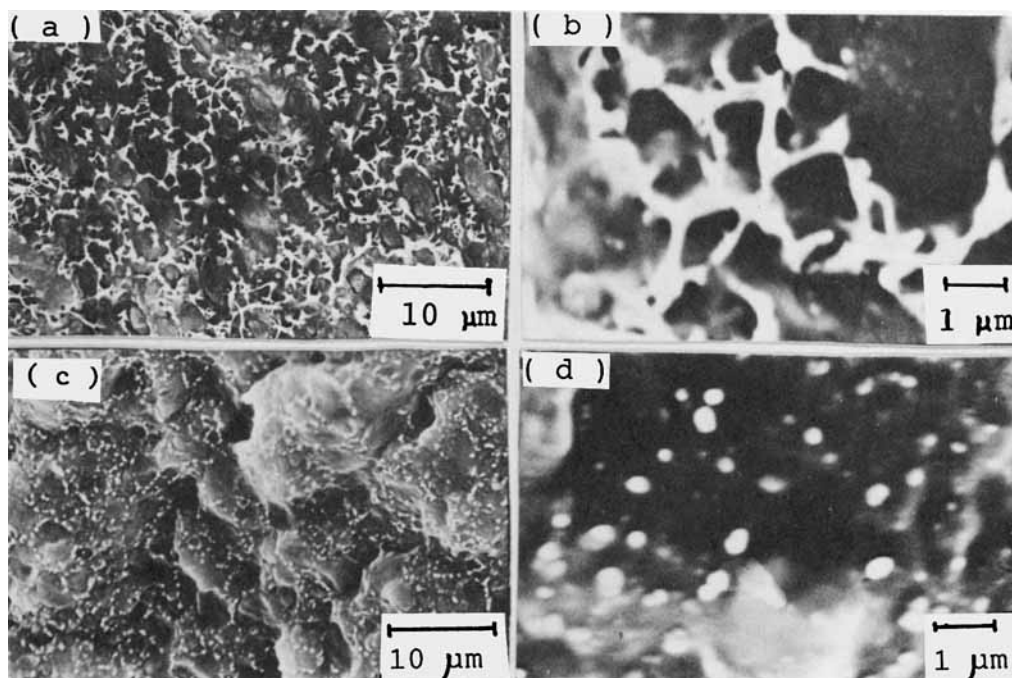


Fig. 11. SEM micrographs of the dynamically cured RB25E75 ternary blends prepared at 60 rpm; the effect of DCP concentration: (a) 0.33 phr ( $\times 2600$ ); (b) 0.33 phr ( $\times 15,000$ ); (c) 1.00 phr ( $\times 2600$ ); (d) 1.00 phr ( $\times 15,000$ ).

The stabilizing effect by crosslinking is more evidently observed for HDPE-rich RB25E75 blends, as shown in Figure 11. At lower DCP content the EPDM domains are interconnected, but at higher DCP content the EPDM particle is spherical in shape. It is apparent that the domain of EPDM might be stabilized at 2–4  $\mu\text{m}$  in size during the dynamic curing process when DCP content is higher.

#### EPDM/PP/HDPE Ternary Blends of 50 and 75 wt % EPDM

The morphology of the ternary linear blends of 50 wt % EPDM (RL50-designated samples) is shown in Figure 12. For these samples, the irregularly shaped HDPE and PP domains are dispersed in EPDM matrix.

The morphology of the RL50 designated blends is somewhat different from that of the RL25 designated blends and the phase-separated structure is more evident in RL50 designated blends. Comparison of Figures 7 and 12 reveals that the size of the dispersed domain of PP and HDPE is larger in the RL50 designated samples.

Figure 13 shows the comparison between the linear ternary blend RL50P50 and the dynamically cured RB50P50 under two different shear intensities. The linear blend has the finer dispersion while the dynamically cured blend under low shear (20 rpm) shows distinct and large domains of PP and HDPE. Figure 14 shows the effect of DCP concentration on the morphology of the RB50 designated samples. It is seen that the phase separation is more clearly

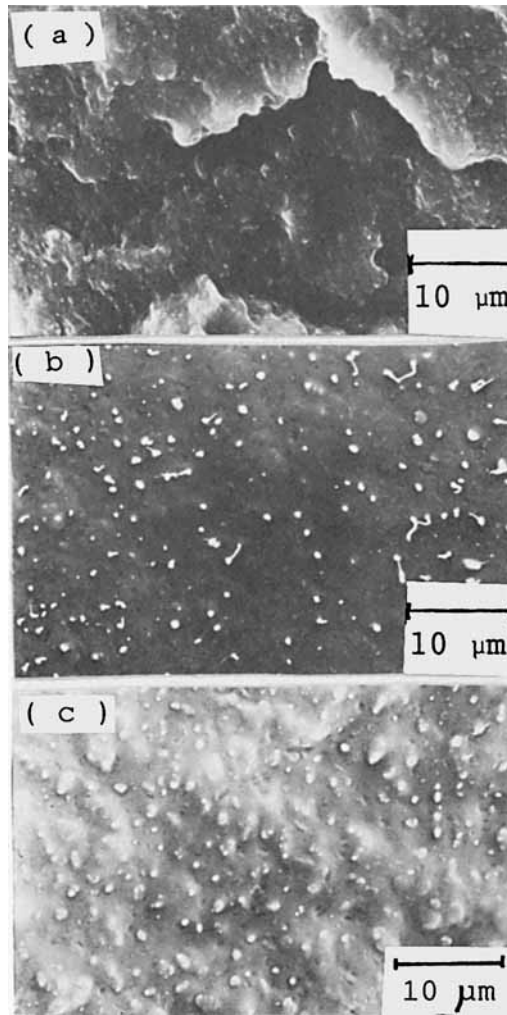


Fig. 12. SEM micrographs of EPDM/PP/HDPE linear ternary blends of 50 wt % EPDM: (a) RL50P50; (b) RL50S50; (c) RL50E50.

observed at higher DCP concentration due to their poor compatibility between the components for both RB50P50 and RB50E50 blends.

The effect of DCP concentration on the morphology of RB50 designated samples is different from the RB25 designated samples. When EPDM is dispersed in PP or HDPE matrix, as in RB25 designated samples, the stabilizing effect by crosslinking is dominant, but when EPDM forms the matrix phase, as in the RB50 designated samples, the phase separation effect becomes dominant between the EPDM matrix and PP or HDPE domain due to the crosslinking in the matrix phase.

The SEM micrographs of the EPDM-rich linear blends (RL75 designated samples) are shown in Figure 15. Small particles of HDPE and PP domains are dispersed in EPDM matrix. However, in the dynamically cured blends of RB75P25 and RB75E25, the identification of PP and HDPE domains

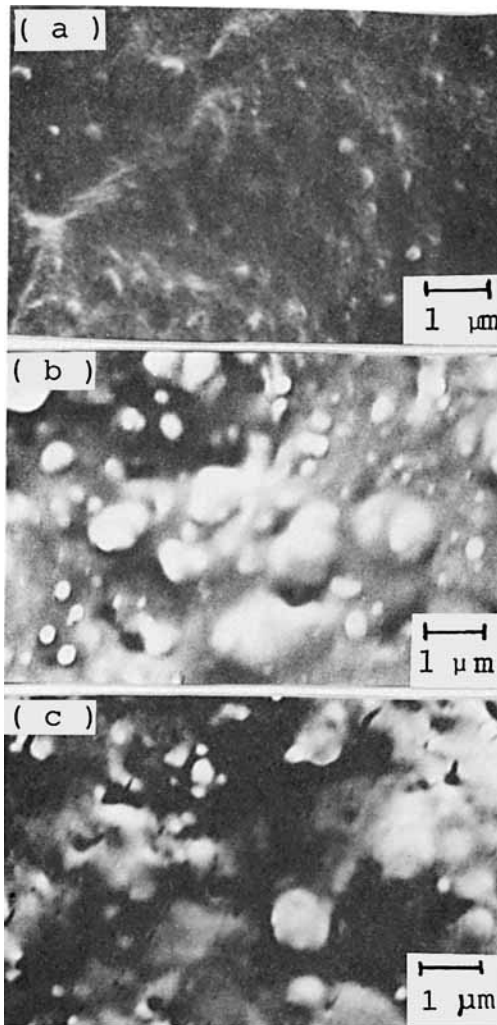


Fig. 13. SEM micrographs of EPDM/PP/HDPE ternary blends of 50 wt % EPDM; (a) RL50P50; (b) RB50P50 (mixer speed 20 rpm; DCP 0.67 phr); (c) RB50P50 (mixer speed 60 rpm; DCP 0.67 phr).

is difficult, and the blends look homogeneous even at high magnification (Fig. 16). The cracks shown in the micrographs are due to the volume contraction in the EPDM matrix during quenching in liquid nitrogen.

### SUMMARY

This study reveals the influences of the blend composition, peroxide content, and intensity of the shear mixing on the tensile properties and the morphology of the dynamically cured EPDM and PP/HDPE ternary blends.

It was found that the tensile strength and the modulus decrease with increasing DCP concentration in the PP-rich blends of 25 wt % EPDM. The decrease in the tensile properties for the PP-rich blends was ascribed to the

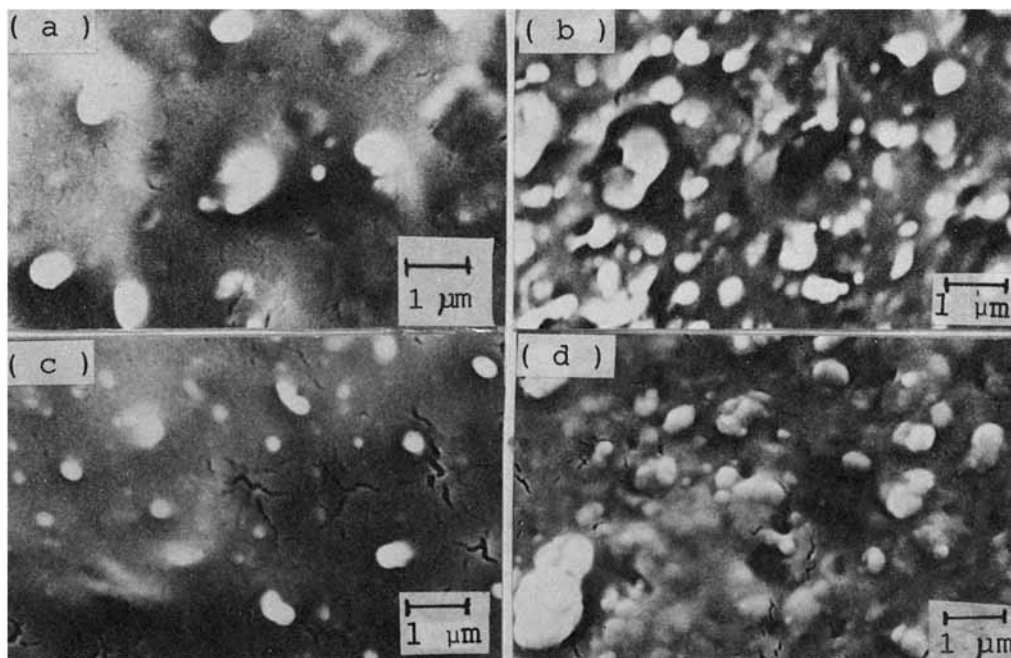


Fig. 14. SEM micrographs of the dynamically cured RB50P50 and RB50E50 ternary blends prepared at 60 rpm; the effect of DCP concentration: (a) RB50P50, DCP 0.33 phr; (b) RB50P50, DCP 1.00 phr; (c) RB50E50, DCP 0.33 phr; (d) RB50E50, DCP 1.00 phr.

mechanochemical degradation of PP by shear and peroxide during the dynamic curing process.

It was also revealed from the morphological analysis by scanning electron microscopy (SEM) that dynamic curing process could reduce and stabilize the domain size of the crosslinked EPDM when the composition of EPDM is 25 wt %. The effect is prominent when DCP concentration is higher or the intensity of the shear mixing is higher. The phase separation effect becomes dominant between the EPDM matrix and PP/HDPE domain due to the crosslinking in the matrix when the EPDM forms the matrix in the blends of the EPDM composition of more than 50 wt %.

Even though it would be required to deduce the accurate mechanism for the tensile properties as a function of the morphology, we did not attempt such an undertaking in the present study but summarized some of the important factors to be related to the mechanism. Those factors affecting independently and simultaneously the tensile properties and the morphology of the blends studied include the decreasing crystallinity of PP or HDPE with blending with EPDM, the mechanochemical degradation of PP by peroxide and shear, the chemical crosslinking of EPDM by peroxide, and even the morphological changes by the various process conditions of the dynamic curing themselves, etc.

Further studies will be made in more detail and reported elsewhere.

The authors wish to thank Mr. Nam Gyun Yun for his help in SEM experiments.



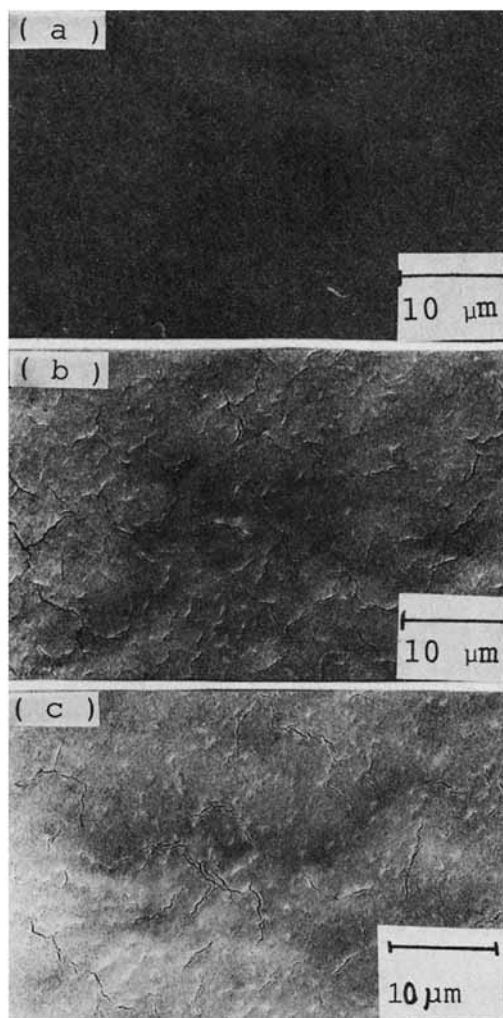


Fig. 15. SEM micrographs of EPDM/PP/HDPE linear ternary blends of 75 wt % EPDM: (a) RL75P25; (b) RL75S25; (c) RL75E25.

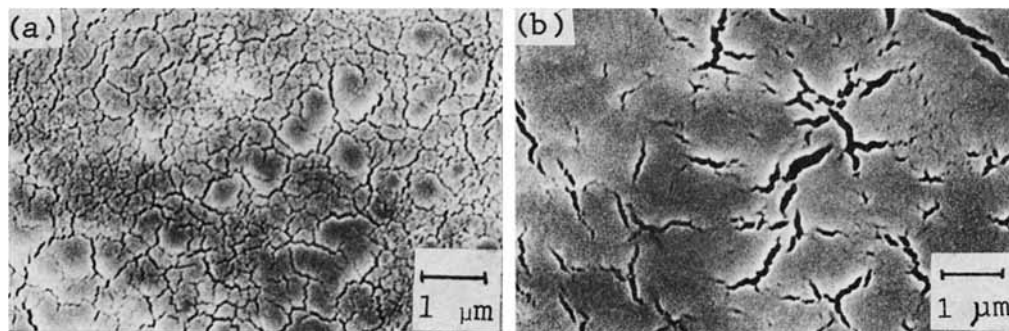


Fig. 16. SEM micrographs of the dynamically cured RB75P25 and RB75E25 ternary blends prepared at 60 rpm with DCP concentration of 0.67 phr: (a) RB75P25; (b) RB75E25.

## References

1. C. S. Ha and S. C. Kim, *J. Appl. Polym. Sci.*, to appear.
2. W. K. Fischer, U.S. Pats., 3,758,693 (1973) and 3,835,201 (1974).
3. W. K. Fischer, U.S. Pat., 3,862,106 (1975).
4. E. N. Kresge, in *Polymer Blends*, D. R. Paul and S. Newman, Eds., Academic, New York, 1978, Vol. II, Chap. 20.
5. L. H. Sperling, *Interpenetrating Polymer Networks and Related Materials*, Plenum, New York, 1981.
6. A. Y. Coran and R. Patel, *Rubber Chem. Technol.*, **56**, 210 (1983).
7. A. J. Lovinger and M. L. Williams, *J. Appl. Polym. Sci.*, **25**, 1703 (1980).
8. L. D. D'orazio, R. Greco, et al., *Polym. Eng. Sci.*, **22** (9), 536 (1982).
9. L. D. D'orazio, R. Greco, E. Martsucelli, and R. Ragosta, *Polym. Eng. Sci.*, **23** (9), 489 (1983).
10. D. W. Bartlett, J. W. Barlow, and D. R. Paul, *J. Appl. Polym. Sci.*, **27**, 2351 (1982).
11. W. E. Chiu and S. J. Fang, *J. Appl. Polym. Sci.*, **30**, 1473 (1985).
12. M. M. Dumoulin, C. Farha, and C. A. Utracki, *Polym. Eng. Sci.*, **24**, 1319 (1984).
13. N. K. Kalfoglou, *J. Macromol. Sci. Phys.*, **B22** (3), 343, 363 (1983).
14. J. Karger-Kocsis, A. Kallo, and N. Kuleznev, *Polymer*, **25**, 279 (1984).
15. R. C. Thamm, *Rubber Chem. Technol.*, **50**, 24 (1977).
16. R. W. Salovey, J. Ho, A. Naderi, and A. J. Chomppf, *Polym. Prepr., Am. Chem. Soc., Div. Polym.*, **20**, 516 (1979).
17. F. C. Stehling, T. Huff, C. S. Speed, and G. W. Wissler, *J. Appl. Polym. Sci.*, **26**, 2693, 1981.
18. E. Helfand and Y. Tagami, *J. Polym. Sci., B*, **9**, 741 (1971).
19. S. Krause, *J. Macromol. Sci., Macromol. Chem.*, **C7** (2), 251 (1972).
20. K. C. Dao, *J. Appl. Polym. Sci.*, **27**, 4799 (1982).
21. K. C. Dao, TIS Report 81-PLA-002, General Electric Co., 1981.

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