

# Effects of Electron Beam Irradiation on the Structure–Property Behavior of Blends Based on Low Density Polyethylene and Styrene-Ethylene-Butylene-Styrene-Block Copolymers

Magdy M. H. Senna,<sup>1</sup> Yasser K. Abdel-Moneam,<sup>2</sup> Yousry A. Hussein,<sup>3</sup> Abdallah Alarifi<sup>1</sup>

<sup>1</sup>Chemistry Department, Catalytic Chemistry Chair, Faculty of Science, King Saud University, Riyadh, Saudi Arabia

<sup>2</sup>Chemistry Department, Faculty of Science, Menoufia University, Sheben Al-Kom, Egypt

<sup>3</sup>Alfanar Electrical Systems, Riyadh, Saudi Arabia

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**ABSTRACT:** Low density polyethylene (LDPE) blends with different additives were exposed to various doses of electron beam irradiation. The additives used were styrene-ethylene-butylene-styrene-block copolymers (SEBS), styrene-ethylene-butylene-styrene-block copolymer grafted with maleic anhydride (SEBS-g-MA) and mineral compounds. The structure–property behavior of electron beam irradiated blends was characterized in terms of mechanical, thermal, and electrical resistivity properties. The results indicated that the unirradiated LDPE blends with the different compositions showed improved mechanical properties, thermal and volume resistivity properties than pure LDPE. However, the improvement in properties of

unirradiated blends by using SEBS-g-MA was higher than using SEBS copolymer. Further improvement in the mechanical, thermal and electrical properties of the LDPE blends was achieved after electron beam irradiation. The limited oxygen index (LOI) data revealed that the LDPE/SEBS-g-MA/ATH blend was changed from combustible to self-extinguishing material after electron beam irradiation to a dose of 100 kGy. © 2012 Wiley Periodicals, Inc. *J Appl Polym Sci* 125: 2384–2393, 2012

**Key words:** LDPE; SEBS; SEBS-g-MA graft copolymer; electron beam irradiation; inorganic fillers

## INTRODUCTION

Developments in the field of polymer blends were raised in the last decade due to property profiles not found in any single polymer. However, when two or more polymers are mixed, the most frequent result is a system that exhibits almost total phase separation due to the limited solubility of one in another. Thus, useful technical properties generally require that the different polymers are sufficiently compatible to give blends in which the interfacial area between the polymer phases is large and phase distribution is stable.<sup>1</sup>

Thermoplastic elastomers constitute a new class of polymeric materials that have a large number of applications due to their unique combination of mechanical properties and processability. The modulus values is comparable with that of reinforced-vulcanized rubbers covering the range of low tempera-

ture near the glass transition temperature of the rubbery component to the higher temperature approaching the melting or softening point of the plastic component. During the processing, thermoplastic elastomers are in a melt state such that they can be processed with plastic processing equipment. Tri-block copolymer is a special one of thermoplastic elastomers, in which styrene–ethylene–butylene–styrene block copolymer (SEBS) is one of the widely used thermoplastic elastomers. SEBS exhibits balanced elasticity, processability, good thermal stability.<sup>2</sup> Thus, it was applied in adhesives, automotive and sport industries. It was established that irradiation of crosslinkable polymers improves thermal stability and mechanical properties, in which most of the properties of low-density polyethylene (LDPE) were improved greatly after irradiation but it was hardened and split easily at low temperature.<sup>3,4</sup> In blending SEBS with LDPE and polypropylene, radiation technology can be used as a tool, not only for polymer surface modification (e.g., grafting), but also for reactive compatibilization.<sup>5–7</sup> The main advantage of the application of high-energy radiation in polymer blends is the formation of strong bridges between macromolecules. Compatibilization of polymer blends by high energy radiation of polymer blend can be achieved without the addition of

Correspondence to: M. M. H. Senna (magdysenna@hotmail.com).

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any ionomer, and in presence of multifunction monomers, which they are effective in accelerating and increasing the crosslinking degree.<sup>8</sup> On the other hand, the compatibilization by radiation of different systems has been a topic of interest and the technique has been used efficiently and economically for the production of new or modified polymers.<sup>9</sup> It was found that SEBS is partially compatible with LDPE but also improves the dielectric constant and dissipation factor of LDPE.<sup>10</sup> The compatibilization of SEBS can be achieved by using grafted SEBS. In some polymer composites, maleic anhydride grafted styrene-ethylene-butylene-styrene block copolymer (SEBS-*g*-MA) is used as a compatibilizer to improve the dispersion of fillers in polymer matrix and enhance the interaction and interfacial adhesion between filler and polymer matrix, consequently improves the properties of polymer composites.<sup>11</sup>

In this work, the effect of electron beam irradiation, styrene-ethylene-butylene-styrene-block copolymers (SEBS), styrene-ethylene-butylene-styrene-block copolymer grafted with maleic anhydride (SEBS-*g*-MA) and mineral compounds on the structure-property behavior of low density polyethylene was studied. The main objective was to improve the thermal, mechanical, insulating properties, and fire retardancy properties of the LDPE/SEBS blends by electron beam radiation crosslinking, especially in presences of inorganic fillers.

## EXPERIMENTAL

### Materials

Low density polyethylene (LDPE) in the form of pellets was received from Exxon Mobil Chemical, USA (grade No. LD: 166BA). The apparent density and melt flow index were 0.923 g/cm<sup>3</sup> and 13 g/10 min, respectively. Styrene-ethylene-butylene-styrene block copolymer (SEBS) and styrene-ethylene-butylene-styrene graft copolymer SEBS-*g*-MA in the form of pellets was received from Asahi Kasei Chemicals, Japan. Titanium dioxide (TiO<sub>2</sub>) with commercial grade (Cristal 134) was obtained from Cristal, KSA. Aluminum hydroxide (ATH) with particle size 0.6–3.2 μm was obtained from Nabaltec GmbH, Germany.

### Preparation of LDPE blends

The blends were prepared by melt mixing of LDPE pellets, with different ratios (15, 20 wt % of the block copolymer styrene-ethylene-butylene-styrene-block copolymer (SEBS), styrene-ethylene-butylene-styrene-block copolymer grafted with maleic anhydride (SEBS-*g*-MA) (5wt %), and inorganic compounds (2–40 phr) in a Barbender plasticorder PL2100 mixer with 50 cm<sup>3</sup> volume capacity. The mixing was per-

formed under the following conditions: mixing temperature 185°C; rotation speed 60 rpm and mixing time 15 min. The films were obtained by compression molding under hot press (Saspol made by Costuruzioni Meccaniche, Italy) at temperature of 185°C for 5 min. The pressure of hot press is kept constant at a 3000 kg/cm<sup>2</sup> for all samples.

### Electron beam irradiation

Irradiation was carried out on the electron beam accelerator (1.5 MeV, 30 mA, and 37.5 kW) facility installed at the National Center for Radiation Research and Technology, Cairo, Egypt. The current and conveyer speed were adjusted to give a total dose of 25 kGy. The higher irradiation doses were obtained by multiple passes.

### FTIR spectroscopic analysis

IR analysis was carried out using an FTIR spectrometry Model Mattson (GenSsis) made by Unicam, England, over the range 400–4000 cm<sup>-1</sup> at a resolution of 4 cm<sup>-1</sup>. High signal to noise spectra were obtained by the collection of 100 scans for each sample.

### Thermogravimetric analysis

Thermogravimetric analysis (TGA) studies were carried out using a Shimadzu-60 (TGA-60) at a heating rate of 10°C/min under nitrogen atmosphere from room temperature up to 600°C.

### Differential scanning calorimetry

Differential scanning calorimetry (DSC) measurements were performed using a Shimadzu DSC-60 calorimeter. A heating rate of 10°C/min was used and the scans were carried out under a flowing nitrogen atmosphere at a rate of 20 mL/min from room temperature up to 150°C.

### Tensile mechanical properties

Mechanical tests including tensile strength and elongation at break points were performed at room temperature using Materials Tester from Rheometric scientific, England, employing a crosshead speed of 20 mm/min. The mechanical properties of the samples were tested in the form of strips of 5 cm in length and 0.4 cm in width. The recorded value for each mechanical parameter is the average of five measurements according to ASTM D-638 standards.

**TABLE I**  
**FTIR Assignments of Absorbance of IR Bands**  
**of Pure LDPE and SEBS<sup>12-15</sup>**

Absorbance band (cm <sup>-1</sup> )	Assignments
LDPE	
700	CH <sub>2</sub> rocking vibration
743 and 1300	amorphous region
1461	crystalline region
3000	CH <sub>2</sub> stretching vibration
SEBS	
697	Out of plan C—H in the aromatic ring
720	Aliphatic C—H bending vibrations
750	Deformation of C—H in aromatic ring
1018	C—C stretch from PS unit
1305	Methylene wagging deformation
1461	Asymmetric methyl bending vibration
1601	PS unit
1736	C=O symmetric stretch

### Scanning electron microscope

The morphology of the fracture surfaces of LDPE blends were examined by scanning electron microscopy (SEM) model-JSM-5400 electron microscope made by JEOL, Japan. A sputter coater was used to precoat conductive gold onto the fracture surfaces before observing the micrographs.

### Rheological measurements

Rheological measurements were performed using GEMINI-2 rheometer (Malvern, Bohlin Instruments, Worcestershire, UK) with parallel plate geometry (plate diameter 25 mm, gap 1.1 mm). Dynamic frequency sweep tests were executed in the frequency range of 0.01–100 rad/s. The temperature for testing was 200°C.

### Hot set test

The hot set test was carried out in a hot set oven (Atsfaar SPA F110 model, Germany). The samples in the form of dumbbell shape were placed in the oven under a definite static load (20 N/mm<sup>2</sup>) at 200°C, and the elongation between two marks was measured after 15 min. The permanent elongation percent (Ep %) after cooling the samples at ambient temperature, was also determined.

### Electrical properties

The volume resistivity was measured according to the ASTM D257 specification using the Teraometer, CEAST, Italy.

### Limiting oxygen index

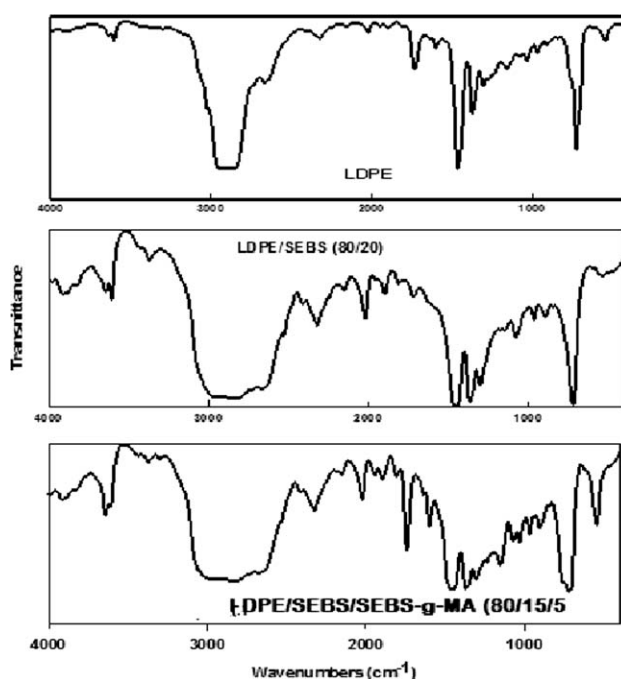
Limiting oxygen index (LOI) tests were performed using an apparatus from Rheometric Scientific, UK and the recorded value for each sample is the average of three measurements in accordance with ASTM D 2863.

## RESULTS AND DISCUSSION

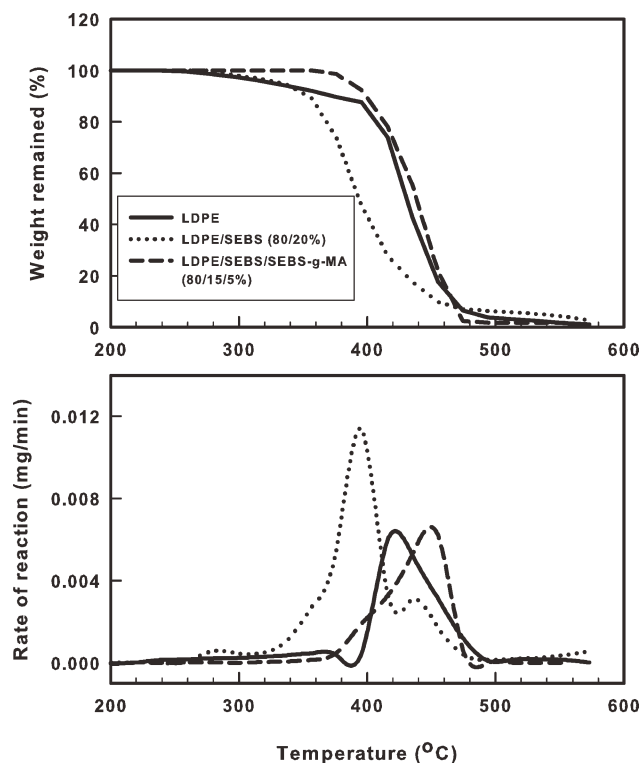
### FTIR spectroscopic analysis

FTIR is one of the most common techniques used for the determination of chemical functional groups within a compound. The assignments of the most typical bands of pure LDPE and SEBS as reported in literature<sup>12-15</sup> are shown in Table I. In LDPE polymer, the characteristic bands at 743 and 1300 cm<sup>-1</sup> were attributed to the amorphous region, while the single band at 1461 cm<sup>-1</sup> was characterized for the crystalline region. Also, the band at 3000 cm<sup>-1</sup> is attributed to CH<sub>2</sub> stretching. The characteristic bands of SEBS showed a predominant absorbance band associated with carboxylic acids and/or aliphatic esters at 1712 cm<sup>-1</sup>.

As shown in Figure 1, for the IR spectra of LDPE/SEBS (80/20%) blend, there is an absorbance band in the range of 1600–1500 cm<sup>-1</sup>, whereas the aromatic C—C ring stretching vibrations can not be detected. The absorbance band at 1492 cm<sup>-1</sup> is attributed to the phenyl group in polystyrene.<sup>16</sup> Also a sharp absorbance band at 697 cm<sup>-1</sup> due to the styrene moiety present in SEBS elastomers can be seen. On the other



**Figure 1** IR spectra for pure LDPE and its blends.



**Figure 2** TGA thermograms and the rate of thermal decomposition reaction versus temperature for unirradiated LDPE and its blends with SEBS and SEBS-g-MA.

hand, the IR spectrum of LDPE/SEBS/SEBS-g-MA (80/15/5) blend showed two bands at 1786 and 1863  $\text{cm}^{-1}$ , which they attributed to the C=O stretching of the maleic anhydride group. The absorbance band at 722  $\text{cm}^{-1}$  is attributed to the C-H bending frequency of anhydride group from SEBS-g-MA polymer.

### Thermal decomposition behavior

Thermogravimetric analysis (TGA) is commonly used to investigate the thermal stability of polymers over a wide range of temperatures. Figure 2 shows the TGA thermograms and the corresponding rate of thermal decomposition reaction curves for unirradiated LDPE and its blends with SEBS and SEBS/

SEBS-g-MA copolymers. It can be seen that the thermal decomposition of LDPE and LDPE/SEBS (80/20%) blend starts at  $\sim 300^\circ\text{C}$ , whereas the thermal decomposition of the blend LDPE/SEBS/SEBS-MA (80/15/5%) starts at  $\sim 400^\circ\text{C}$ . The decomposition temperatures corresponding to different weight loss (%) are shown in Table II. The weight loss (%) indicates higher thermal stability for LDPE/SEBS/SEBS-MA (80/15/5%) blend compared to pure LDPE and LDPE/SEBS (80/20%) blend. It can be seen that the rate of thermal decomposition reaction curves for all the samples goes through one maximum over the entire range of temperatures. The different thermal decomposition temperatures such as  $T_{\text{initial}}$ ,  $T_{\text{max}}$ , and  $T_{\text{final}}$  from the rate of decomposition reaction curves are shown in Table II. The table indicated that the LDPE/SEBS/SEBS-MA (80/15/5%) blend displayed higher  $T_{\text{max}}$  than that for LDPE and LDPE/SEBS (80/20%) blends. Similar trends can be observed by comparing  $T_{\text{initial}}$ .

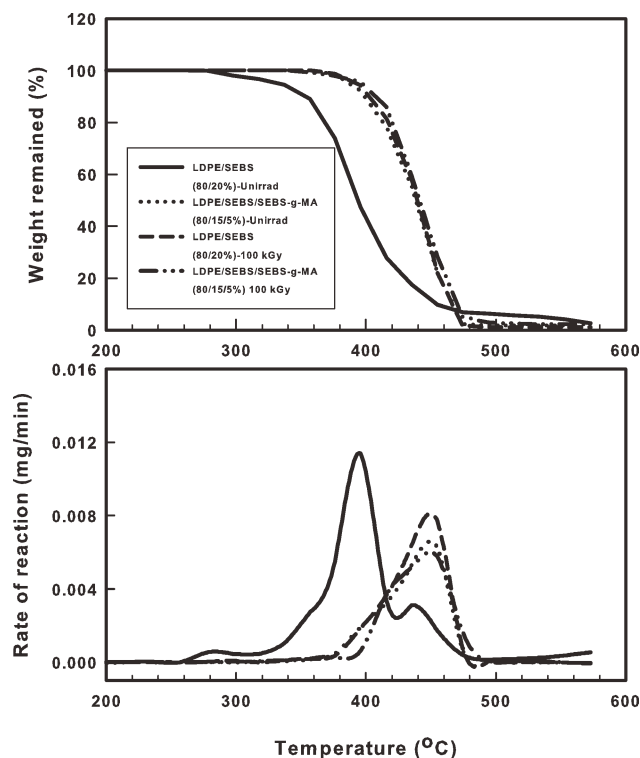
The thermal stability of any polymeric material is largely affected by the strength of the covalent bonds between the atoms forming the polymer molecules. The dissociation energy for the different covalent bonds C-H, C-C, C-O, O-H, and C=C was reported to be 414, 347, 351, 464, and 611 kJ/mol, respectively.<sup>17</sup> On the basis of these values, the average bond dissociation energy for LDPE, SEBS, and SEBS-MA is calculated to be 400, 412, and 431 kJ/mol. Thus it may be conclude that SEBS possesses higher thermal stability than LDPE and that blends of LDPE with any ratio of SEBS will eventually results in higher thermal stability than pure LDPE. However, the results for SEBS are not in accordance with the theoretical values as in case of LDPE/SEBS/SEBS-MA (80/15/5%) blend. The limited macromolecular chain mobility as a result of the formation of intermolecular crosslinks between blend components (in case of SEBS-MA) was also expected to increase the thermal stability.

Figure 3 shows the TGA thermograms and the corresponding rate of thermal decomposition reaction of LDPE/SEBS (80/20%) and LDPE/SEBS/SEBS-MA (80/15/5%) blends after electron beam

**TABLE II**  
Decomposition Temperatures at Different Weight Loss (%) for Different LDPE Blends

LDPE blends	Dose (kGy)	Decomposition temperature at different weight loss ( $^\circ\text{C}$ )					$T_{\text{initial}}$ ( $^\circ\text{C}$ )	$T_{\text{max}}$ ( $^\circ\text{C}$ )	$T_{\text{final}}$ ( $^\circ\text{C}$ )
		10%	20%	40%	80%	90%			
LDPE (100%)	0	381	420	432	461	474	270	492	420
	100	385	420	445	463	472	316	502	425
LDPE/SEBS (80/20%)	0	355	370	389	331	455	286	485	395
	100	416	429	445	468	474	383	482	448
LDPE/SEBS/SEBS-MA (80/15/5%)	0	409	422	441	465	472	371	481	450
	100	423	432	446	472	465	372	488	455





**Figure 3** TGA thermograms and the rate of thermal decomposition reaction versus temperature of LDPE blends with SEBS and SEBS-g-MA before and after electron beam irradiation at a dose of 100 kGy.

irradiated at dose of 100 kGy. An improvement in the thermal properties of LDPE/SEBS (80/20%) blend after electron beam irradiation is observed, in which the thermal decomposition of this blend or the LDPE/SEBS/SEBS-MA (80/15/5%) blend starts at higher temperatures. Also, the maximum value of the rate of decomposition reaction ( $T_{max}$ ) indicates clearly that the electron beam irradiated blends possess higher thermal stability than unirradiated blends. The improvement in thermal stability associated with electron beam irradiation can be attributed to crosslinking of the blend components.<sup>18–20</sup>

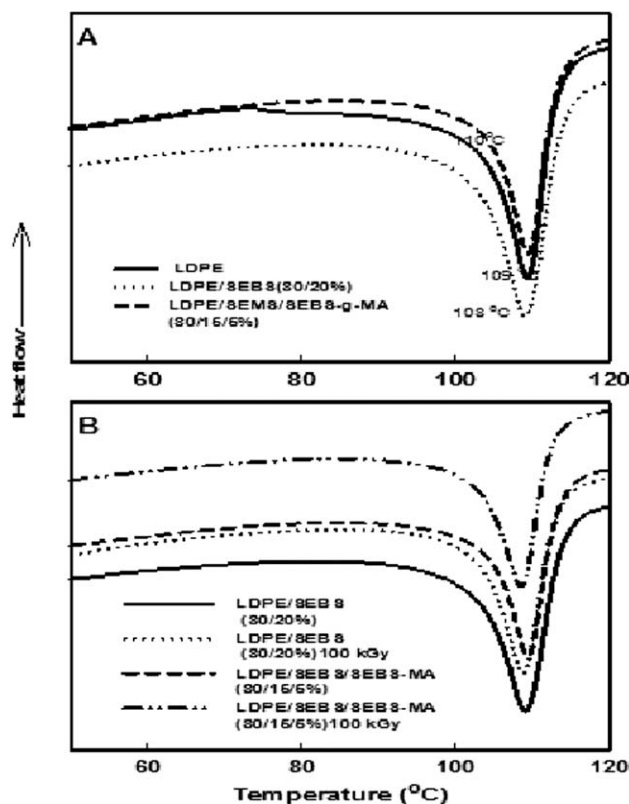
### Differential scanning calorimetry

DSC is one of the convenient methods for investigating the thermal properties in terms of compatibility of polymer blends. It was used to investigate the effect of SEBS blending with LDPE and electron beam irradiation on the melting transitions temperature as shown in Figure 4. It can be seen that LDPE polymer showed a main melt temperature (endothermic peak) at 110°C, whereas the DSC scans showed that the LDPE/SEBS and LDPE/SEBS/SEBS-MA blends displayed endothermic peaks at lower melting temperature than LDPE polymer. This decrease in melting temperature may be due to the interaction that may occur between the glassy moi-

ety of the PS polymer in the SEBS copolymer and the crystalline part of the semi-crystalline LDPE polymer.<sup>21,22</sup> The endothermic peak corresponding to the melting temperature of irradiated blends was decreased and this induced by the decrease in crystalline part of irradiated the polymer blends.

### Mechanical properties

Mechanical properties are one of the most important properties of all the physical properties of high polymers for most applications. There are many structural factors, which affect the mechanical behavior of polymeric materials. In addition to the chemical composition, molecular weight, crosslinking and branching, crystallinity and crystal morphology, copolymerization, plasticization, molecular orientation, and fillers are structural factors, which affect the mechanical properties.<sup>23</sup> The mechanical properties for LDPE, LDPE/SEBS, and LDPE/SEBS/SEBS-g-MA blends were carried out and the data are given in Table III. From Table III, it can be seen that the blending of SEBS or SEBS-g-MA to the unirradiated blends results in increasing the break stress and strain. In this respect, break strain of LDPE was increased from 517% to 731 and 737% by blending SEBS and SEBS/SEBS-g-MA, respectively. As shown



**Figure 4** DSC Thermograms of: (A) unirradiated LDPE/SEBS and LDPE/SEBS/SEBS-g-MA blends, (B) electron beam irradiated blends at a dose of 100 kGy.

**TABLE III**  
**Mechanical Properties of Pure LDPE and Its Blends EB Irradiated to Different Doses**

LDPE blends	Dose (kGy)	Tensile mechanical at break	
		Stress (MPa)	Strain (%)
LDPE (100%)	0	16.0	580
	50	21.8	517
	75	20.1	474
	100	26.2	558
LDPE/SEBS (80/20%)	0	18.0	731
	50	17.0	556
	75	16.5	490
	100	15.7	472
LDPE/SEBS/SEBS-g-MA (80/15/5%)	0	17.3	737
	50	15.0	320
	75	15.0	385
	100	20.7	468

in Table III, electron beam irradiation to low doses 50 and 75 kGy causes a relatively decrease in the mechanical properties of LDPE blends. This is due to the presence of styrene groups that acts as energy dissipation, which decreases the effect of radiation on the LDPE phase. Also, the presence of the branched CH<sub>3</sub> in the butylene elastomer phase acts as weak point (as in case of PP) in the blend matrix.

Table IV shows the tensile mechanical properties of the LDPE/SEBS/SEBS-g-MA/TiO<sub>2</sub> and LDPE/SEBS/SEBS-g-MA/ATH blends, before and after electron beam irradiation to various doses. It can be seen that the break stress was increased, whereas the strain was decreased after electron beam irradiation to the dose 100 kGy. However, the tensile properties of LDPE/SEBS-MA/inorganic fillers was remained higher than unirradiated LDPE and LDPE/SEBS-MA blends (Table III) with a slight decrease in break strain values. Also, increasing the inorganic filler concentration decreases the mechanical properties of LDPE.

**TABLE IV**  
**Mechanical P of LDPE/SEBS/SEBS-g-MA Blends Containing Inorganic Fillers**

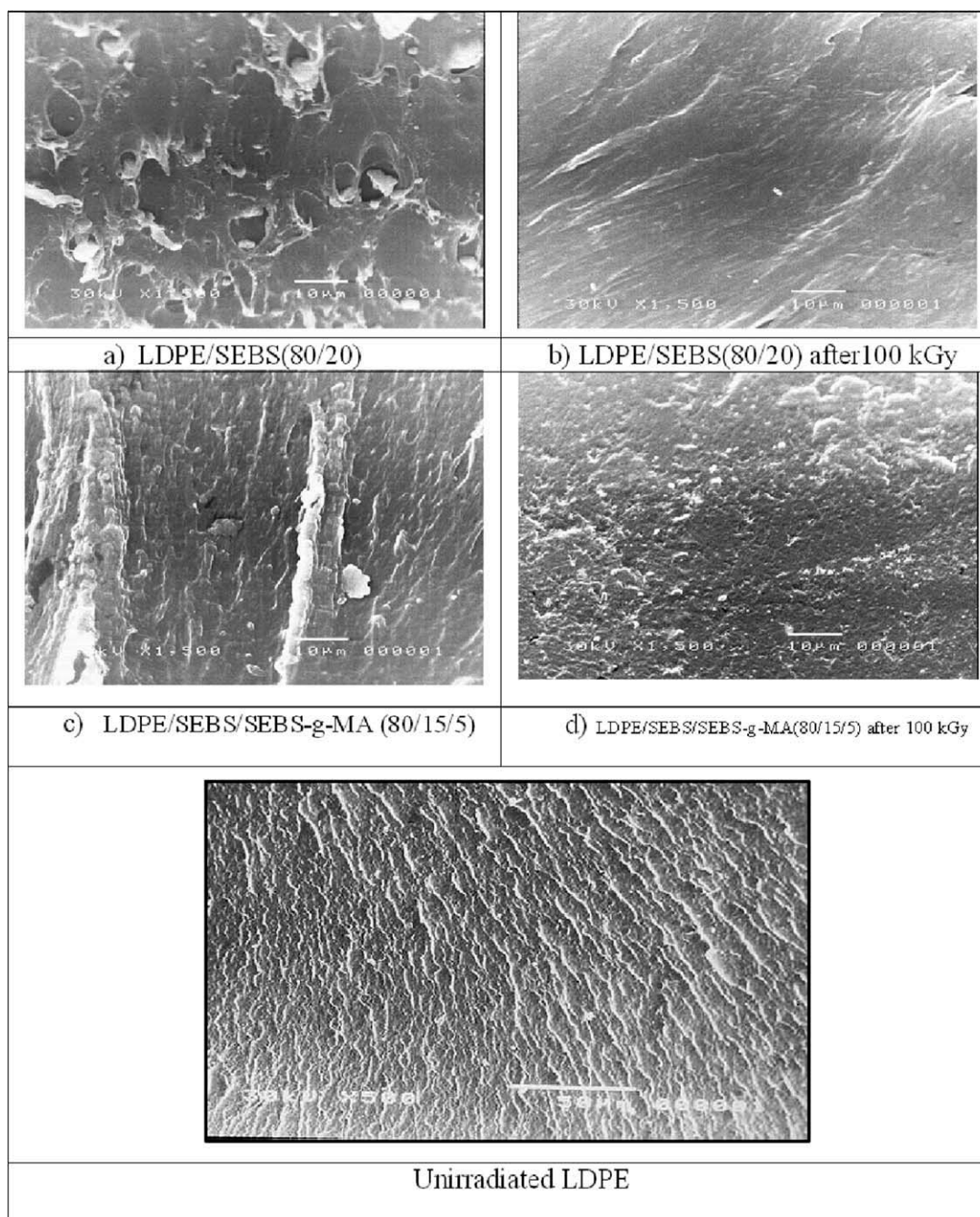
LDPE blends	Dose (kGy)	Mechanical properties at break	
		Stress (MPa)	Strain (%)
LDPE/SEBS/SEBS-g-MA/TiO <sub>2</sub> (2 phr) (80/15/5%)	0	18	700
	100	24	757
LDPE/SEBS/SEBS-g-MA/TiO <sub>2</sub> (4 phr) (80/15/5%)4 phr	0	11	460
	100	20	660
LDPE/SEBS/SEBS-g-MA/ATH (20 phr) (80/15/5%)	0	17.5	582
	100	21	663
LDPE/SEBS/SEBS-g-MA/ATH (40 phr) (80/15/5%)	0	13.8	432
	100	15.5	485

### Structure morphology (SEM)

The examination of morphology of polymer blends by scanning electron microscopy (SEM) provides an evidence for the compatibility occurring in blends. In most cases, the major component of the blend forms the matrix whereas the minor component is the dispersion phase, in which the mechanical properties of the polymer blends depend on the phase dispersion and the phase size as well. Samples of the LDPE, LDPE/SEBS, and LDPE/SEBS/SEBS-g-MA blends were examined by using SEM, before and after exposure to electron beam irradiation as shown in Figure 5. LDPE is a typical semicrystalline polymer; hence there are two expected types of interfaces in LDPE/SEBS blends: the interface between the amorphous and crystalline phases of semicrystalline LDPE polymer and the interface between the two polymer domains.<sup>24</sup> The electron beam irradiation of LDPE blends provides finer, uniform, and stable phase morphology compared with the unirradiated blends as shown in Figure 5(b,d). These changes may be caused mainly due to the presence of macro radicals generated by irradiation.<sup>25</sup> These macro radicals could react at the boundary surfaces of the different phases and consequentially, the adhesion between these phases was increased and more uniform surfaces were produced.

### Rheological properties

As for most polyolefins, it has been proven that the three dimensional network structures will be formed when the polymers were irradiated. The structure of crosslinked network was determined with the rheological properties measurements, in which the viscosity of the molten polymers are affected by molecular weight and molecular distribution and both will depends on frequency and temperature. Figures 6 and 7 show the storage modulus ( $G'$ ), loss modulus



**Figure 5** SEM of fracture surfaces for: Unirradiated LDPE, (a) unirradiated (LDPE/SEBS), (b) irradiated (LDPE/SEBS) blends, (c) unirradiated (LDPE/SEBS/SEBS-g-MA) blends (d) irradiated (LDPE/SEBS/SEBS-g-MA) blends and LDPE.

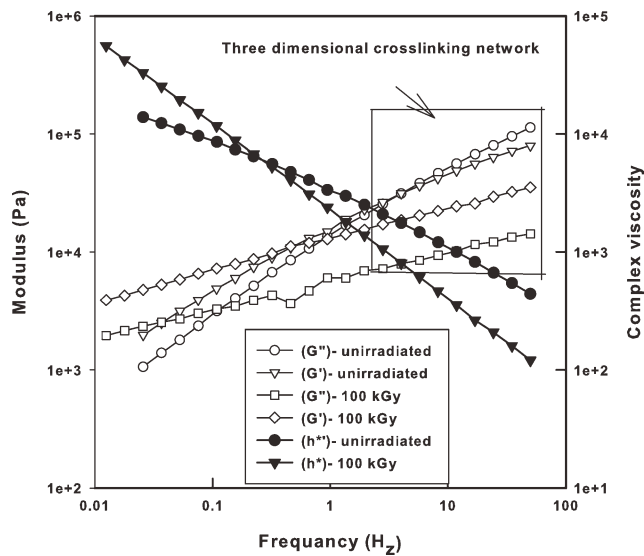
( $G''$ ) and the viscosity ( $\eta$ ) for unirradiated and irradiated LDPE composites measured at 200°C. It can be seen that the plateau region of  $G''$  ( $\omega$ ) indicated that a three-dimensional crosslinking network structure was formed in the composites after irradiation. It can be seen also that the frequency dependence of  $G''$  showed a similar trends. In the high ( $\omega$ ) region,  $G''$  of the unirradiated composite was much higher than those of the irradiated ones. The complex viscosity ( $\eta^*$ ) of the unirradiated composite and the irradiated ones vs. frequency ( $\omega$ ) was shown in Fig-

ure 7. It could be seen that the irradiated composites displayed a much higher complex viscosity and a pronounced shear thinning behavior. The complex viscosity increased with irradiation dose, inferring that the gel content was increased. But the unirradiated composite showed more pseudo-Newtonian behavior in low ( $\omega$ ) regime.

#### Hot set test

As can be seen in the above section, the rheological properties of molten LDPE and LDPE blends were





**Figure 6** Melt rheological properties of unirradiated and electron beam irradiated LDPE (100%) measured at 200°C. ( $G'$ ) Storage modulus, ( $G''$ ) Loss modulus, and ( $\eta^*$ ) Complex viscosity.

changed after irradiation. According to the theory of elasticity, the crosslink density ( $\nu$ ) of polymers can be predicted in terms of the number of crosslinks per unit volume ( $\text{mol}/\text{cm}^3$ ) from the strain (%) at 200°C, and is expressed by the following relation<sup>26</sup>:

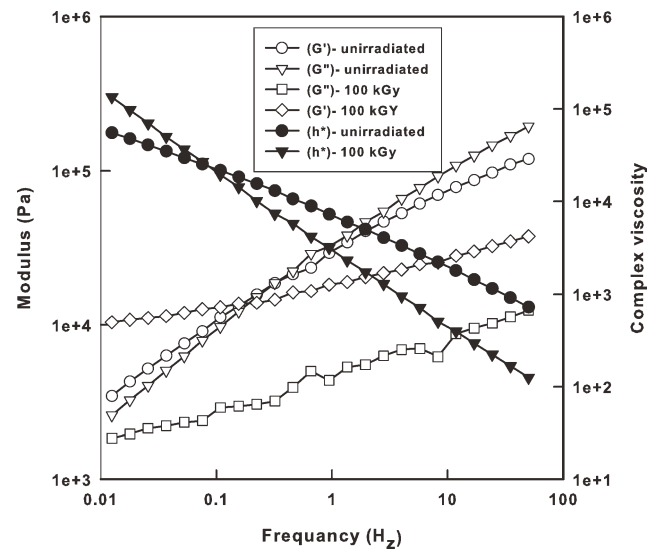
$$G = \nu RT$$

Where ( $G$ ) is the shear modulus of the polymer which is approximately one-third of tensile modulus ( $E$ ),  $R$  is the gas constant (8.314 J/mol K) and  $T$  is the absolute temperature (K). The tensile modulus ( $E$ ) can be calculated in hot set test as follow:

$$E = \sigma/\varepsilon$$

Where ( $\sigma$ ) is the tensile stress and ( $\varepsilon$ ) tensile strain after 15 min.

Hot set test was carried out for unirradiated and irradiated LDPE blends at different ratios. It was



**Figure 7** Melt rheological properties of unirradiated and EB-irradiated (LDPE/SEBS /SEBS-g-MA)-ATH (80/15/5%-20 phr) composites measured at 200°C. ( $G'$ ) Storage modulus, ( $G''$ ) Loss modulus, and ( $\eta^*$ ) Complex viscosity.

found that the unirradiated samples and the 100 kGy irradiated LDPE are failed after 1, and 10 min, respectively. The hot set test for the 100 kGy irradiated blends is listed in Table V. It can be seen that the blends containing SEBS and inorganic fillers were succeeded to pass the test exhibiting higher crosslink density higher than the 100 kGy irradiated LDPE and the data were in accordance with the obtained results in rheological measurement at (200°C).

### Electrical properties

As shown in Table VI, the value of volume resistivity of pure LDPE was increased upon electron beam irradiation to doses of 50, 75, and 100 kGy from  $6 \times 10^{15}$  to  $17.8 \times 10^{15}$ ,  $14.3 \times 10^{15}$ , and  $17.8 \times 10^{15} \Omega$  cm, respectively. In addition, it is clear that the values of volume resistivity were higher in the cases of unirradiated LDPE/SEBS and LDPE/SEBS/SEBS-g-

**TABLE V**  
Crosslink Density and Hot Set Data for LDPE Blends of Different Compositions

LDPE blends	Strain after 15 min ( $L_1$ ) cm	Strain (%)	Crosslink density, $\nu$ (mol/L)
LDPE/SEBS (80/20)	41.70	317	0.5384
PE/SEBS/MA (80/15/5)	46.70	367	0.4619
LDPE/SEBS/SEBS-g-MA/TiO <sub>2</sub> (2 phr) (80/15/5%)	47.15	377	0.4485
LDPE/SEBS/SEBS-g-MA/TiO <sub>2</sub> (4 phr) (80/15/5%)	38.90	289	0.5866
LDPE/SEBS/SEBS-g-MA/ATH (20 phr) (80/15/5%)	30.16	200	0.8476
LDPE/SEBS/SEBS-g-MA/ATH (40 phr) (80/15/5%)	28.35	183	0.9213

Operating temperature = 200°C, for 15 min, Original length of species ( $L$ ) = 10 cm, Irradiation dose = 100 kGy.



**TABLE VI**  
**Volume Resistivity and LOI Properties for Pure LDPE**  
**and Its Blends of Different Compositions**

LDPE blends composition (%)	Doses (kGy)	Volume resistivity ( $\Omega$ cm) $\times 10^{15}$	LOI (%)
LDPE	0	6.0	17.5
	100	17.8	17.8
LDPE/SEBS (80/20)	0	18.6	
	100	16.2	
LDPE/SEBS/SEBS-g-MA (80/15/5)	0	23.0	17.8
	100	17.8	18.7
LDPE/SEBS/SEBS-g-MA/TiO <sub>2</sub> (2 phr) (80/15/5 %)	0	12.0	
	100	15.0	
LDPE/SEBS/SEBS-g-MA/TiO <sub>2</sub> (4 phr) (80/15/5%)	0	17.0	
	100	19.7	
LDPE/SEBS/SEBS-g-MA/ATH (20 phr) (80/15/5%)	0	13.0	18.8
	100	15.0	21.9
LDPE/SEBS/SEBS-g-MA/ATH (40 phr) (80/15/5%)	0	11.0	
	100	12.5	

MA blends than pure LDPE. The data reveal that when SEBS and SEBS-g-MA are blended with pure LDPE they provide more insulating properties. Electron beam irradiation was enhanced the volume resistivity of pure LDPE and decreases the volume resistivity of LDPE blends but they still possess higher values than that of pure LDPE. As shown in Table VI, the volume resistivity for LDPE/SEBS/SEBS-g-MA blends were decreased with adding the TiO<sub>2</sub> and ATH, but also, these values were increased after electron beam (EB) irradiation at 100 kGy. The volume resistivity value at the dose 100 kGy may be related to the higher crosslink density, in which the average molecular weight of LDPE and its blends were increased. Presence of large crosslinking points can be considered as barrier to prevent the charge movement between polymer chains and thus increase the electrical resistance of crosslinked samples.<sup>27,28</sup>

### Flame retardant properties

LOI is one of the most important screening and quality control method used in plastic industry. The value of the LOI is defined as the minimal oxygen concentration [O<sub>2</sub>] in the oxygen/nitrogen mixture [O<sub>2</sub>/N<sub>2</sub>] that either maintains flame combustion of the material for 3 min or consumes a length of 5 cm of the sample, with the sample placed in a vertical position (the top of the test sample is inflamed with a burner).

The LOI is expressed as:

$$\text{LOI} = \left\{ \frac{[\text{O}_2]}{([\text{O}_2] + [\text{N}_2])} \right\} \times 100$$

The flame response of unirradiated LDPE blends in comparison with 100 kGy irradiated samples was

evaluated by limited oxygen index (LOI) test. It can be seen from Table VI, that the LOI values were increased with addition of SEBS-MA/ATH to LDPE, but this increase was higher in cease of adding ATH with compatibilizing agent (SEBS-MA). Also, irradiation of these blends improves the flame retardancy properties than irradiated LDPE alone. The LOI value of LDPE/SEBS-g-MA/ATH- 100 kGy was more than 21 which indicates the flame retardancy improvement of this composite with low level of ATH and irradiation. Materials with an LOI below 21 are classified as "combustible" whereas those with an LOI above 21% are classified as "self-extinguishing," because their combustion cannot be sustained at ambient temperature without an external energy contribution and the higher LOI the better the flame retardant property.

### CONCLUSIONS

From the above, it can be conclude that the addition of styrene-ethylene-butylene-styrene-block copolymers (SEBS) and maleic anhydride grafted styrene-ethylene-butylene-styrene-block copolymers (SEBS-g-MA) to LDPE improves the thermal, mechanical, and electrical properties compared with those for pure unirradiated LDPE. Also, using electron beam irradiation improves these properties through free radical formation at boundary surfaces for blend different components. The LOI was improved by using low concentration of ATH in irradiated LDPE/SEBS-MA blend.

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