

Biodegradation of Low-Density Polyethylene/Thermoplastic Starch Foams Before and After Electron Beam Irradiation

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ABSTRACT: Foamy low-density polyethylene/plasticized starch (LDPE/PLST) blends at different compositions were produced in the presence of azodicarbonamide (ACA) compound as foaming agent. The LDPE/PLST blends before and after electron beam irradiation were investigated in terms of mechanical properties, bulk density, and structure morphology. Moreover, the biodegradability of these materials was evaluated by the soil burial test for 2 months, in which the buried sheets were also examined by scanning electron microscopy (SEM). The results showed that the increase of PLST content from 24 to 30% was accompanied by a decrease in the yield and break stresses of 10 and 20% for the unirradiated blends

without the foaming agent, respectively. Further decrease in these mechanical parameters was observed after the foaming process. The bulk density, void fraction, cell size measurements as well as the examination by SEM illustrate clearly the cell growth of the foam structure. The soil burial test and SEM micrographs indicate the growth of microorganisms overall the blend sheets and that the blend was completely damaged after two months of burying. © 2007 Wiley Periodicals, Inc. *J Appl Polym Sci* 106: 3273–3281, 2007

Key words: LDPE/PLST blends; foams; electron beam irradiation; mechanical properties; biodegradation

INTRODUCTION

Starch is a naturally occurring polymer, a truly renewable resource, and it is a biodegradable polymer because it can readily be metabolized by a wide range of microorganisms.¹ Unlike other synthetic thermoplastic polymers, starch can be processed into a thermoplastic material in the presence of plasticizers and under the influence of heat.² The blending of biodegradable polymer like starch with a nonbiodegradable polymer as polyethylene may be considered a method for reducing the cost of the materials and for modifying the biodegradation rate. Biodegradation is the natural process, in which the degradation of materials results from the action of naturally occurring microorganisms such as bacteria, fungi, and algae.³ Biodegradable plastics break down completely into nonplastic and nontoxic constituent substances like water, CO₂, CH₄, and biological materials. It is known that biodegradation is not significant in the first step of the biodegradation of polyethylene, which has a good resistance to microorganisms.⁴ In

this regard, the preparation and characterization of LDPE/plasticized starch blends in the presence of ethylene/vinyl acetate copolymer as compatibilizing agents was investigated by different analytical methods.⁵ The results showed that the mechanical properties especially the elongation at break were satisfactory even for blends containing higher amounts of starch. In addition, the biodegradability of polyethylene/starch blends was studied under marine exposure conditions.⁶ The process ability and physical properties of thermoplastic blends with poly(ethylene-co-vinyl alcohol) were studied.⁷ Moreover, the effect of polyethylene grafted with maleic anhydride on the compatibility of LDPE/starch blends was reported.^{8,9} It was shown that the compatibilized blends have only a slightly lower biodegradation rate compared to the blends without compatibilizing agents.

Plastic foam is commonly used for describing a two-phase system of a gas dispersed in a solid plastic.¹⁰ The ultimate arrangement of solid and gas in plastic foam is governed predominantly by the interrelationship of three forces existing during the expansion of plastic. These forces are: the pressure of the gas inside the voids or cells forcing the plastic in the cell walls to flow as the cell volume increases, surface tension forces that cause the flow of plastic from the

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cell walls to the points at which they intersect, and the counterbalancing viscoelastic retroactive force of the plastic, restricting its flow.¹¹ Foam whose cells are discrete, or noninterconnecting, and whose gas phase is not continuous is designated "closed-celled." The present work was undertaken to study the effect of electron beam irradiation on the physicochemical and biodegradation properties of low-density polyethylene/plasticized starch (LDPE/PLST) foamed blends.

EXPERIMENTAL

Materials

Low-density polyethylene (LDPE) was supplied by Qatar Petrochemical Company, Qatar. Maize starch used throughout this study was supplied by the Egyptian Company for Starch and Glucose, Cairo, Egypt. Ethylene/vinyl acetate copolymer (EVA), a laboratory grade, was kindly obtained from TPI Polyene Public Company, Thailand. Polyethylene graft copolymer with maleic anhydride (PEMA) is the product of Uni Royal Chemicals, USA and it was solid under the commercial name Polybond. Glycerol, chemical grade, was used as received. Azodicarbonamide (ACA), a laboratory grade, was used as a blowing agent and was purchased from BDH, Germany.

Preparation of plasticized starch

Plasticized starch (PLST) was prepared by treating maize starch with 17 wt % of glycerol and subsequently dissolved in water with continuous stirring and heating at 90°C for 15 min. The plasticized starch was obtained and left to dry in air, vacuum oven at 50°C for 24 h.

Preparation of LDPE/PLST blends

PLST was melt-blended with LDPE at various ratios in a Brabender Plasticorder PL 2100 Mixer at 170°C, 60 rpm, and for 15 min. In all LDPE/PLST blends, the LDPE pellets were mixed with constant ratios of the compatibilizers EVA at 25 wt % and PEMA at 2 wt %. The LDPE/PLST films were prepared by compression-molding under a hot press at 150°C for 7 min.

Electron beam irradiation

Irradiation was carried out on the electron beam accelerator (1.5 MeV, 30 mA) facility installed at the National Center for Radiation Research and Technology, Cairo, Egypt. The required doses were obtained by adjusting the conveyer speed and current parameters to give a total dose of 10 kGy per each pass, in which the total irradiation doses of 30 and 50 were obtained by multiple passes.

Foaming of LDPE/PLST blends

The foam structure of crosslinked LDPE/PLST blends was obtained by heating the sheets at 195°C for 15 min. This process was done by placing the sheets on the heated lower plate of a hot press. The average thickness of LDPE/PLST before foaming was ranging from 0.93 to 1.01 mm, while the thickness after foaming was ranging from 1.6 to 2.7 mm.

Tensile mechanical properties

Mechanical tests including tensile strength, elongation at yield, and break points were performed at room temperature using an Instron Machine (model 1195) employing a crosshead speed of 10 mm/min. The recorded values for each mechanical parameter were the average of five measurements according to ASTM D-638 standards.

Scanning electron microscopy

The morphology of the fracture surfaces of the different LDPE/PLST blends was examined by SEM. The SEM micrographs were taken with a JSM-5400 electron microscope, JEOL, Japan. A sputter coater was used to precoat conductive gold onto the fracture surfaces before observing the micrographs at 30 kV.

Bulk density measurements

The bulk density was measured according to ASTM D-1505. The recorded values were the average of three measurements.

Soil burial test

The biodegradation of the LDPE/PLST blends was tested by the soil burial test. In this method, naturally fertile top soil is placed in a dry wooden box to a depth of at least 13 cm. The soil was brought to the optimum moisture content by gradual addition of water and mixing. The sheets were buried horizontally such that the samples were uniformly covered with the soil. The samples were buried for periods up to 2 months. The buried samples were gently washed and air-dried at room temperature for 24 h. The deterioration caused in the foam structure by the attack of microorganisms was taken as an indication for the biodegradability of the samples.

RESULTS AND DISCUSSION

Characterization of unfoamed LDPE/PLST blends

In the present work, the compatibility of LDPE/PLST was improved by using the reactive compounds PEMA and EVA as compatibilizers. During the blend-

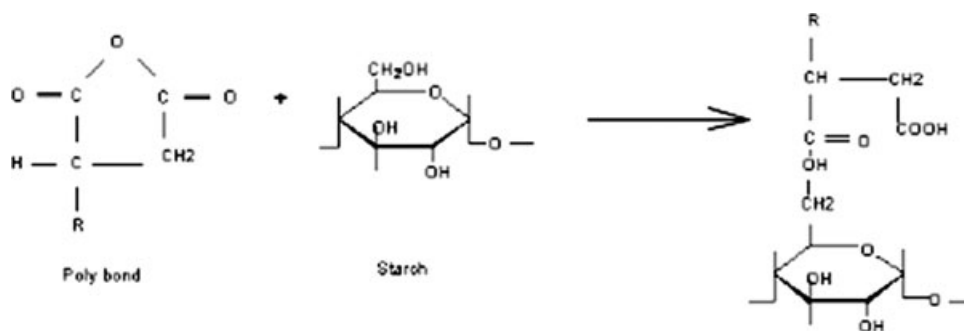


Figure 1 Reaction mechanism of PEMA compatibilizer with starch.

ing of LDPE and plasticized starch in the presence of PEMA compatibilizer, the anhydride groups of PEMA can react with the hydroxyls of starch to form ester linkages.¹² The carboxylic groups, arising from

the hydrolyzed anhydride, can also form hydrogen bonding with the hydroxyl groups. The pathway of the reaction between starch and PEMA can be proposed as shown in Figure 1.

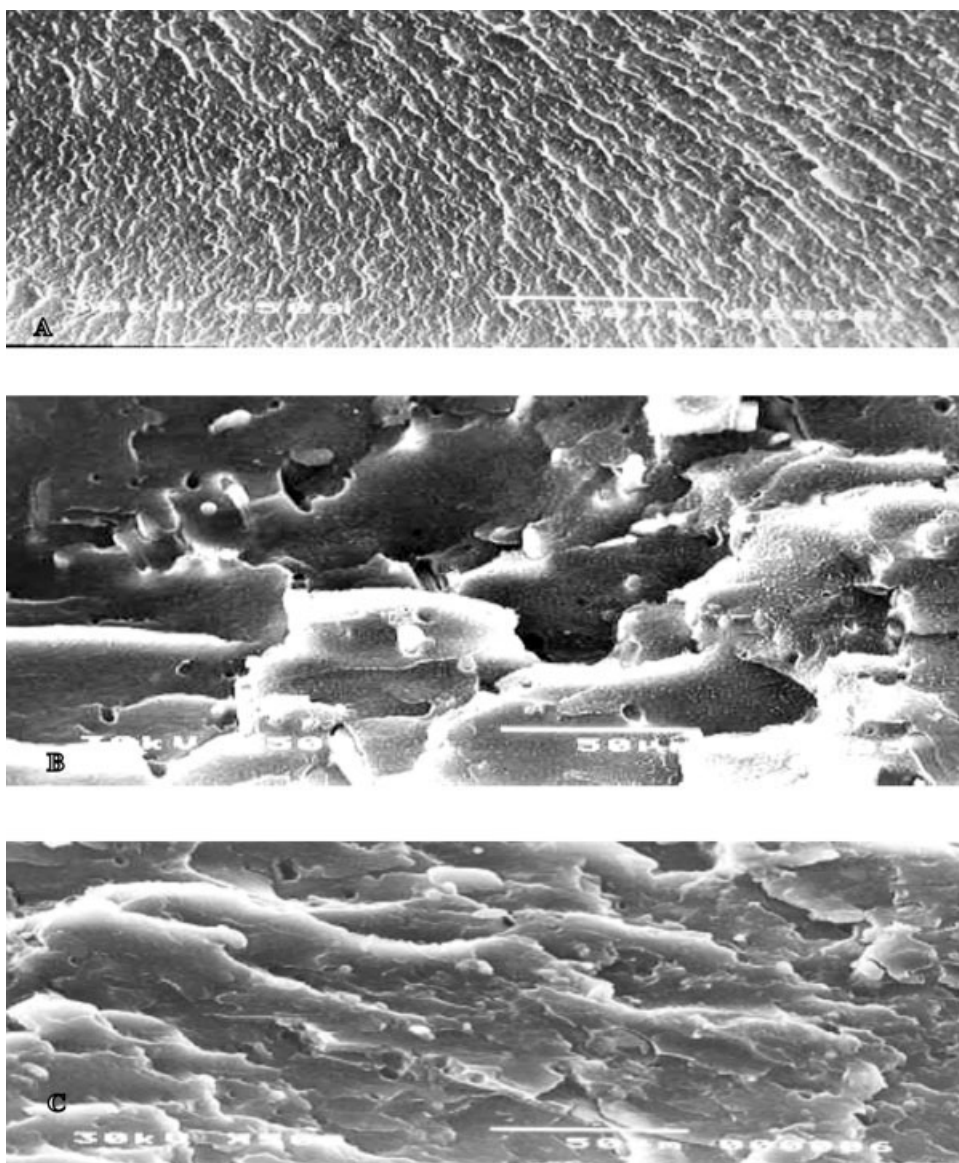


Figure 2 SEM micrographs of (A) unirradiated LDPE, (B) unirradiated unfoamed LDPE/PLST (70/30), (C) unfoamed LDPE/PLST (70/30) irradiated to 30 kGy.

Structure morphology

Figure 2 shows the SEM micrographs of the fracture surfaces of unirradiated pure LDPE and LDPE/PLST (70/30%) blend exposed to 30 kGy of electron beam irradiation. As can be seen from Figure 2(A), the fracture surface of pure LDPE is not smooth and characterized with uniform continuous matrix. However, the SEM micrographs of LDPE/PLST blends showed a different surface morphology, in which the surface is rough with different texture and changes. The effect of compatibilizers is very clear, in which it is difficult to distinguish the PLST phase, which seems to become a part of the whole matrix. It was reported that starch could form a complex when mixed with low molecular weight compounds such as monoglycerides as well as with macromolecular compounds like ethylene acrylic acid compound.¹³ This is the reason why starch can be blended with higher amount of EVA and produces fine dispersed phase. The addition of reactive compatibilizer such as PEMA in the mixing process produces more distribution of the starch phase in the LDPE matrix. The branched and cross-linked macromolecules that are produced between PEMA and the two polymers chains reduce the interfacial tension between them and thus improve the compatibility.

As shown in Figures 2(B) and 2(C), the phase patterns for the blend containing 30% PLST decreases after electron beam irradiation to 30 kGy. The decrease in PLST phase size is due to the interconnection between starch molecules and LDPE through the formed free radicals during electron beam irradiation at the boundary surfaces. This interconnection was found to increase with increasing irradiation dose.

Density and mechanical properties

The effect of irradiation dose on the tensile mechanical properties and bulk density of unfoamed LDPE/PLST blends at two compositions is shown in Tables I and II. It should be noted that all the blends contain 25 wt % of EVA and 2 wt % of PEMA (all based on starch weight). The tensile mechanical parameters at yield and break point were calculated from the stress-strain curves. It can be seen that the increase of PLST content from 20 to 30% in the unirradiated blends causes a decrease in the yield and break stresses of 10 and 24 kgf/cm², respectively. While the yield strain was not affected by increasing PLST content from 20 to 30%, the yield break was decreased by ~ 150%. After the exposure to electron beam irradiation, the yield and break stresses of the unfoamed LDPE/PLST blends increases with increasing the electron beam dose up to 30 kGy and then tends to decrease, regardless of the blend composition. On the other hand, the yield and break strains of LDPE/PLST blend containing 30% of PLST was found to decrease substantially with increasing irradiation dose.

For packaging materials based on foam structure, low bulk density is desired to minimize the transportation cost. In this work, the bulk density of LDPE/PLST foams at different ratios was measured using the Archimedes water displacement rule. As shown in Tables I and II, the unirradiated and unfoamed blends containing 30% of PLST possesses a relatively lower bulk density than the blend containing 20% of PLST. However, it can be seen that the increase of tensile parameters associated with increasing irradiation dose was accompanied by a substantial decrease in bulk density, regardless of the blend composition.

TABLE I
Effect of Foaming Agent (ACA) Contents on Density and Tensile Mechanical Properties of LDPE/PLST (80/20) Blend, Before and After Electron Beam Irradiation of Various Doses

FA (%)	Dose (kGy)	Density (g/cm ³)	Yield stress (kgf/cm ²)	Yield strain (%)	Break stress (kgf/cm ²)	Break strain (%)
Without	0	1.12	99 ± 5	20 ± 6	120 ± 5	350 ± 28
	10	0.98	109 ± 7	18 ± 3	150 ± 5	388 ± 35
	30	0.90	110 ± 3	31 ± 7	157 ± 9	436 ± 18
	50	0.86	101 ± 2	17 ± 4	156 ± 9	364 ± 21
1	0	0.30	63 ± 8	17 ± 1.5	40 ± 3	111 ± 0.6
	10	0.37	60 ± 3	4 ± 0.5	37 ± 2	10 ± 0.3
	30	0.55	53 ± 2	3 ± 0.2	27 ± 2	4 ± 0.6
	50	0.70	45 ± 3	3 ± 0.0	17 ± 2	4 ± 0.3
2	0	0.26	55 ± 5	11 ± 0.3	38 ± 3	114 ± 2
	10	0.32	51 ± 3	12 ± 1	37 ± 3	14 ± 1
	30	0.45	45 ± 3	16 ± 0.7	36 ± 3	21 ± 2
	50	0.67	42 ± 4	9 ± 0.3	36 ± 2	16 ± 2
3	0	0.23	33 ± 2	5 ± 0.1	29 ± 2	114 ± 2
	10	0.24	32 ± 1	4 ± 0.2	23 ± 2	10 ± 2
	30	0.33	29 ± 3	2 ± 0.0	20 ± 2	4 ± 0.3
	50	0.42	None	None	23 ± 2	18 ± 2

TABLE II
Effect of Foaming Agent (ACA) Contents on Density and Tensile Mechanical Properties of LDPE/PLST (70/30) Blend, Before and After Electron Beam Irradiation of Various Doses

FA (%)	Dose (kGy)	Density (g/cm ³)	Yield stress (kgf/cm ²)	Yield strain (%)	Break stress (kgf/cm ²)	Break strain (%)
Without	0	1.05	89 ± 10	20 ± 2	96 ± 4	196 ± 22
	10	0.92	103 ± 5	16 ± 4	108 ± 12	180 ± 11.3
	30	0.86	110 ± 6	10 ± 2	92 ± 6	167 ± 12.5
	50	0.80	86 ± 1	8 ± 2	33 ± 4	123 ± 1
1	0	0.28	50 ± 4	17 ± 0.7	37 ± 4	28 ± 0.3
	10	0.35	24 ± 3	4 ± 0.0	31 ± 2	24 ± 3
	30	0.50	33 ± 2	4 ± 0.8	18 ± 0.8	13 ± 1
	50	0.71	None	None	13 ± 0.5	11 ± 0.5
2	0	0.25	33 ± 1.3	14 ± 0.2	33 ± 2	23 ± 0.8
	10	0.30	28 ± 0.8	3 ± 0.6	23 ± 1.1	15 ± 1.6
	30	0.42	22 ± 2	0.4 ± 0.04	20 ± 1.5	10 ± 0.8
	50	0.51	21 ± 1	0.6 ± 0.01	18 ± 2	8 ± 2
3	0	0.20	18 ± 2	7 ± 0.1	27 ± 2	26 ± 1
	10	0.21	20 ± 0.3	2 ± 0.2	13 ± 3	20 ± 3
	30	0.37	19 ± 0.3	0.8 ± 0.01	12 ± 1	18 ± 0.9
	50	0.39	None	None	10 ± 2	11 ± 0.6

Characterization of foamed LDPE/PLST blends

Density and mechanical properties

The foaming agents are usually classified into two types according to their decomposition reaction: endothermic and exothermic.¹⁴ Endothermic foaming agent usually absorbs heat and generates CO₂, whereas the exothermic agents usually release heat and produce N₂ during its decomposition reaction. This chemistry of foaming will influence the viscoelastic properties of the matrix and cell morphology and hence affects the mechanical properties of the foamed sheets. The effect of different contents of the foaming agent on the bulk density of LDPE/PLST blends before and after electron beam irradiation to various doses is shown in Tables I and II. In general, the mechanical parameters of the unirradiated blends were greatly affected by increasing the foaming ratio, regardless of the blend composition. In this regard, the yield stress for the unirradiated foamed blend containing 20% of PLST was decreased by ~ 36, 44, and 67%, whereas the yield strain was decreased by ~ 15, 45, and 55% by increasing the foaming ratio from 1 to 2% and from 2 to 3%, respectively. However, the break stress for the same blend was decreased by 67, 68, and 76%, whereas the break strain was decreased by 68, 67, and 67% by increasing the same ratios of the foaming agents, respectively. For the unirradiated foamed blend containing 30% of PLST, the reduction in the mechanical parameters was higher than those for the blend containing 20% of PLST. The increase of the foaming agent ratio is expected to increase the foam cell size and the foaming density and thus decreases the mechanical parameters.

After the exposure of LDPE/PLST foams to electron beam irradiation, a slight decrease in the differ-

ent mechanical parameters can be observed with respect to the unirradiated foams, regardless of the blend composition. In this regard, the yield and break stresses of the blend foam containing 20%, prepared by using 2% of the foaming agent, were decreased by 18 and 5% upon exposure to a dose of 30 kGy of electron beam irradiation. Similar trends were observed in the case of the blend foam containing 30% of PLST.

For unirradiated foams, it can be seen that the increase of the foaming agent ratio was accompanied with a decrease in the bulk density. This finding can be attributed to the introduction of extra gas to the polymer blends. In addition, it can be seen that the bulk density of LDPE/PLST foams with higher contents of PLST is higher than that for the blends with lower contents of PLST, although the density of starch (1.34 g/cm³) is higher than LDPE (0.92 g/cm³). These trends may result from the fact that the addition of starch to LDPE decreases the melt viscosity of the blend. In this context, the decrease in melt viscosity increases the diffusion of gases through the matrix leading to an increase in the cell growth and hence a decrease in the bulk density occurs. The electron beam irradiation was found to increase the bulk density. This increase is due to crosslinking of LDPE under the effect of electron beam irradiation. The crosslinking increases the compact structure of the blends, and hence increases the bulk density.

Structure morphology

The SEM micrographs of the fracture surfaces for LDPE/PLST (70/30%) foams before and after electron

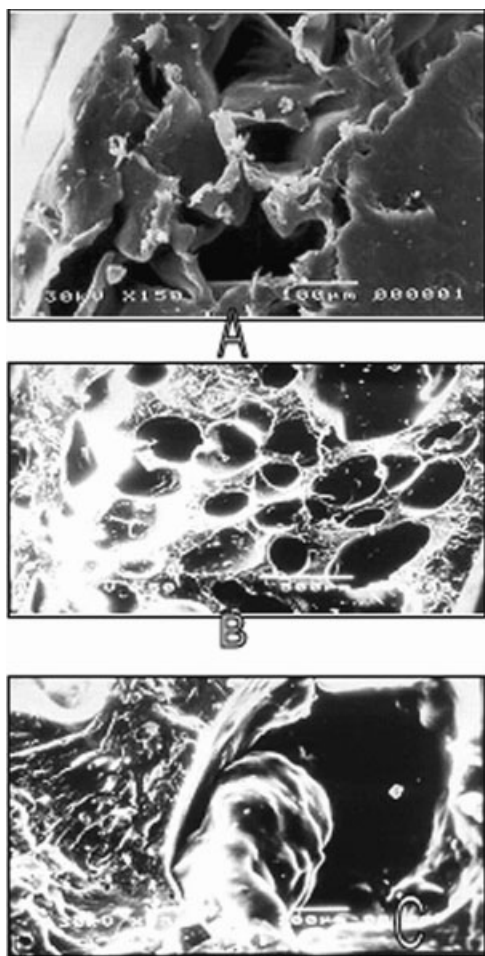


Figure 3 SEM micrographs for LDPE/PLST (70/30%) foams before and after electron beam irradiation to various doses: (A) Unirradiated, (B) 30 kGy, (C) 50 kGy. All blends contain constant ratios of EVA (25%), PEMA (2%), and foamed with a constant ratio of ACA (2%).

beam irradiation to various doses are shown in Figure 3. As shown in Figure 3(A), the fracture surface of the unirradiated foam showed a foam morphology and cell size of orders greater than 100 μm . The starch decreases the melt viscosity of the blend and thus decreases the polymer resistance to cell growth in the polymer blend. This effect can be compared with the SEM micrographs of the samples after irradiation to the doses 30 and 50 kGy as shown in Figures 3(B) and 3(C). In addition to the improved compatibility of LDPE/PLST blends as the result of the use of the reactive compounds PEMA and EVA during mixing, free radicals are expected to form during electron beam irradiation. These free radicals will eventually induce the formation of covalent bonds between the starch and LDPE and thus increase the bonding between the two phases leading to increase of the adhesion and compatibility. This improvement in adhesion prevents the gases to escape from small open cells.

Cell diameter and void fraction

The void fraction (V_f) and nucleation density, which represents the number of cells per unit of unfoamed polymer (N_o) were determined from the SEM micrographs using the following equations:¹⁵

$$V_f = 1 - (\rho_f/\rho)$$

$$N_o = (nM^2/A)^{3/2}(1/1 - V_f)$$

where n is the number of bubble in the micrograph, M is the magnification factor, A is the area of the micrograph, and ρ and ρ_f are the densities before and after foaming.

From the above equation, the cell size (d) can be determined as follows:

$$d = [6V_f/\pi N_o(1 - V_f)]^{1/3}$$

The application of the above equations for the foams under investigation is shown in Figures 4 and 5. The irradiation process causes a clear decrease in the cell diameter for both blend compositions. While cell number was found to decrease with increasing irradiation dose for the blend (70/30%), the cell number was found to increase by increasing irradiation dose in the case of the blend (80/20%).

The effect of irradiation and starch content on the cell size and cell number can be explained based on the mechanism of cell growth. The cell growth is governed by the stiffness of the gas/polymer matrix, the rate of gas diffusion, and the amount of gas loss at a

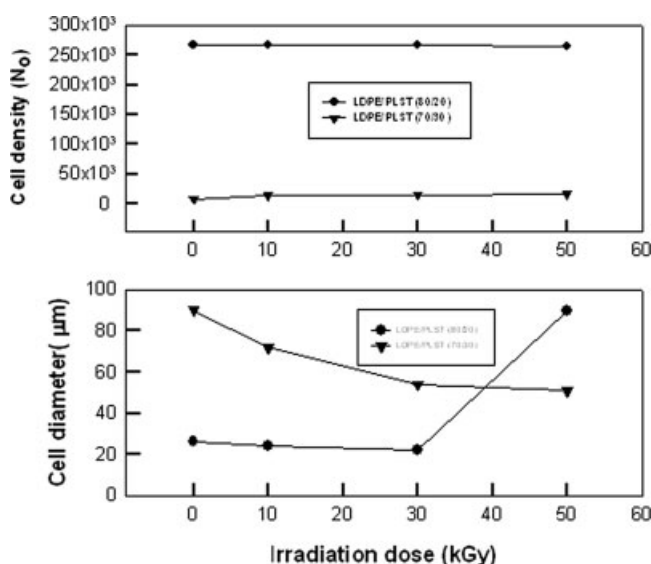


Figure 4 Effect of electron beam irradiation on the cell density and diameter of LDPE/PLST foams at different compositions. All blends contain constant ratios of EVA (25%), PEMA (2%), and foamed with a constant ratio of ACA (2%).

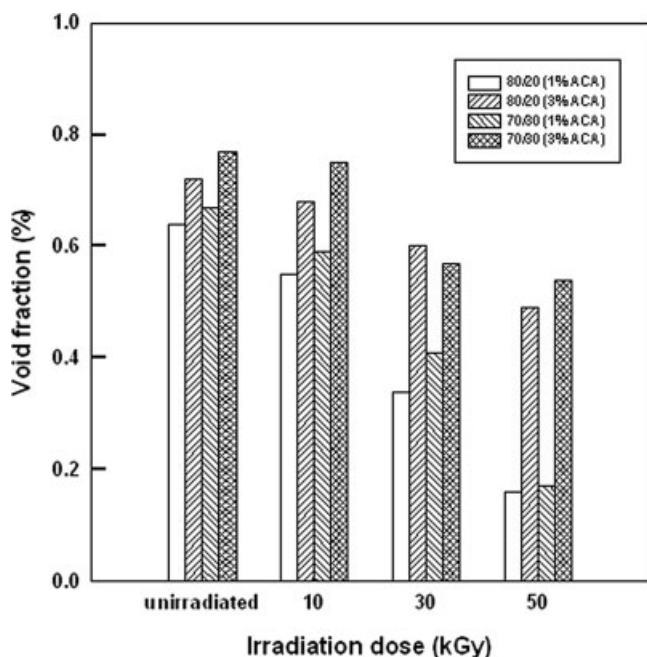


Figure 5 Effect of electron beam irradiation on the void fraction of LDPE/PLST foams at different compositions. All blends contain constant ratios of EVA (25%), PEMA (2%), and foamed with a constant ratio of ACA (2%).

given time and temperature. When the blowing agent decomposes and the gas is evolved, the cells will start to grow and the cell growth will continue until the blowing agent is depleted from the polymer melt. The final cell size is determined by the amount of blowing agent (gas) used for the cell growth and the diffusion of this gas through the cells and the cell walls. At low dose irradiated samples, the melt strength of polymer and its viscosity will increase. When the cell growth occurs because of the diffusion of gas from the blend matrix, the increased viscosity decelerates the thinning of cell walls and consequently, the cell walls will decrease the rate of gas diffusion through the cell wall. As a result, the cell size will decrease and the number of cells will increase. Thus, the increase in the cell size and the decrease in cell number in the case of the blend (70/30%) can be explained. However, the higher starch content decreases the melt viscosity of the blend. This decrease will accelerate the rate of diffusion of gases through the cell wall (the gases are quickly diffused out of the cells), the number of foam cell contracts, and thus the cell size became bigger.

As shown in Figure 5, the void fraction (V_f) of unirradiated LDPE/PLST foams with relatively higher ratios of PLST is slightly higher than that in the case of blends with low PLST ratios. However, for both unirradiated blend foams, the V_f was found to increase with increasing ratio of the foaming agent on the contrary of bulk density. In addition, the V_f decreases greatly with increasing irradiation dose particularly for the blend foam with low PLST content.

Biodegradation properties

Biodegradation is defined as an event, which takes place through the action of enzymes and/or chemical decomposition associated with living microorganisms (bacteria, fungi, yeasts, etc.) or their products. Most synthetic polymers are nonbiodegradable. For example, enzymes that cause the decomposition of polyethylene are absent in nature, whereas starch is a natural polymer that decomposes to repeating units (1,4- α -D-glucopyranosyl units) by enzymes. Microorganisms are spread everywhere; whenever there is some moisture and appropriate nutrient, they will thrive even under severe conditions. Even though unpleasant odor and visual deterioration are indications of the growth of microbes, it is necessary to test the biodegradability of the prepared polymeric foams.

SEM technique was used to observe the deterioration that occurred in the structure morphology as an indication for biodegradability of the prepared LDPE/PLST foams. Figure 6 shows SEM micrographs of the fracture surfaces of unirradiated LDPE/PLST (80/20%) foams before and after being buried in a

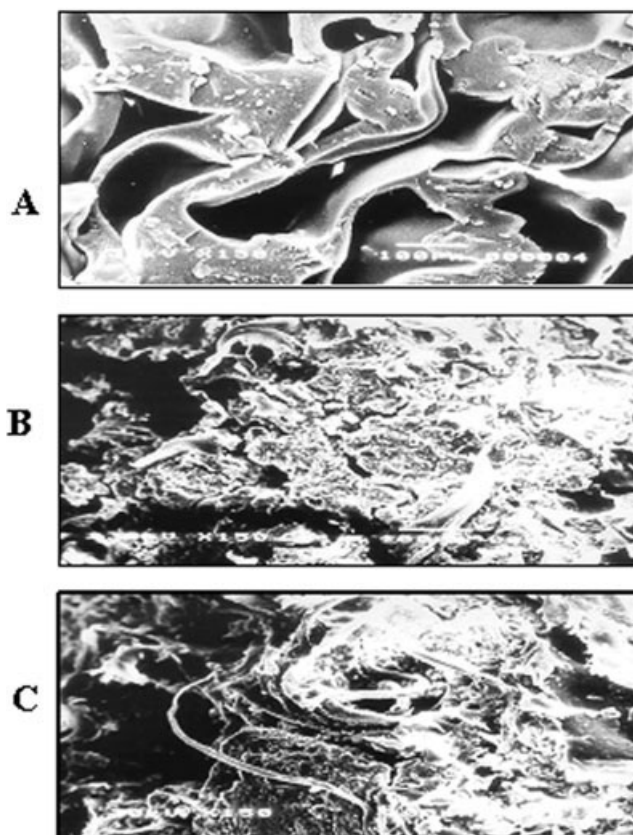


Figure 6 SEM micrographs of the fracture surfaces of unirradiated LDPE/PLST (80/20%) foams buried for different times: (A) before burying, (B) after 1 month, (C) after 2 months. All blends contain constant ratios of EVA (25%), PEMA (2%), and foamed with a constant ratio of ACA (2%).

soil rich in microorganisms, for different lengths of times. It should be noted that all the foams were prepared by using 2 wt % of the blowing agent (ACA) and contain constant ratios of EVA (25 wt %) and PEMA (2 wt %). As shown in Figure 6(B), the foam structure starts to damage after 1 month of burying, and it could not recognize the characteristic shape of the air cells in the foam compared to the foam structure before burying as seen in Figure 6(A). After 2 months, it is difficult to recognize the sample, in which the growth and dispersion of microorganisms were observed on the surface.

The LDPE/PLST foams containing relatively higher contents of PLST (30%) seems highly susceptible to biodegradation by microorganisms even after 1 month of burying as shown in Figure 7. In this regard, the microorganisms grow around the foam cell structure, in which these cells are full of air, which is suitable for the life of microorganisms. After 1 month of burying, the microorganisms seem to grow rapidly and it is difficult to distinguish the foam structure. After 2 months, the blend structure was completely dam-

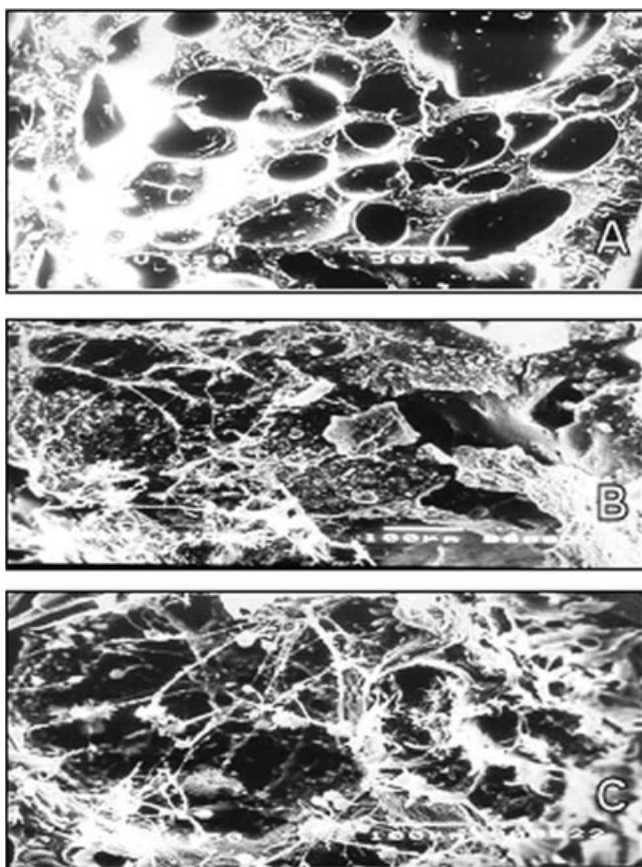


Figure 7 SEM micrographs of the fracture surfaces of unirradiated LDPE/PLST (70/30%) foams buried for different times: (A) before burying, (B) after 1 month, (C) after 2 months. All blends contain constant ratios of EVA (25%), PEMA (2%), and foamed with a constant ratio of ACA (2%).

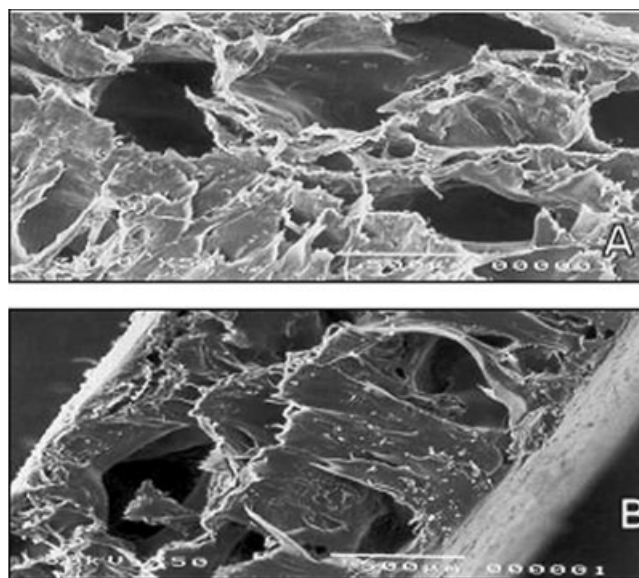


Figure 8 SEM micrograph of the fracture surfaces of electron beam-irradiated LDPE/PLST foams at different compositions to a dose of 30 kGy buried for 2 months: (A) (80/20%), (B) (70/30%). All blends contain constant ratios of EVA (25%), PEMA (2%), and foamed with a constant ratio of ACA (2%).

aged, the surface is full of cracks and holes, and the microorganism colonies seem to cover all the dimensions of the sample. Therefore, it can be recommended that this composition of polymer blend is the most suitable to produce packaging materials.

Figure 8 shows SEM micrographs of the fracture surfaces of LDPE/PLST foams at different ratios previously exposed to a dose of 30 kGy of electron beam irradiation buried in a soil rich of microorganisms for 2 months. It can be seen that the LDPE/PLST foam blends crosslinked by electron beam irradiation are relatively resistant to microorganisms than the unirradiated foams of the same blends. However, the attack of microorganisms was found to increase with increasing content of starch component. This means that the crosslinking of LDPE component could not offer protection toward the attack of microorganisms. However, the crosslinking of LDPE/PLST foams improves the mechanical properties in the stage of usage, which is important.

CONCLUSIONS

The basic approach was to improve the compatibility and biodegradability and minimize the production cost of LDPE/PLST polymer blends. The compatibility was improved by the addition of compatibilizing agent and electron beam irradiation, whereas the biodegradability was improved by preparing the blends in foam structure. However, the improved strength due to the enhanced crosslinking and interfacial

adhesion between the components due to irradiation effect are accompanied by the expense of tensile strength and density of the foamed blends. The SEM micrographs of the buried LDPE/PLST blends for 2 months showed that the foam structure no longer occurs, in which the microorganisms cover the whole surface. In addition, the SEM micrographs showed that the blends containing higher contents of PLST are more susceptible to biodegradation.

References

1. Nayak, P. J. *Macromol Sci Rev Macromol Phys* 1999, C39, 481.
2. Roper, H.; Koch, H. *Starch/Staerke* 1990, 42, 123.
3. ASTM standards on environmentally degradable plastics, ASTM Publication Code Number (PCN) 1993, 003-420093-19.
4. Albertsson, C.; Andersson, S. O.; Karlsson, S. *Polym Degrad Stab* 1987, 18, 73.
5. Prinos, J.; Bikiaris, D.; Theologidis, S.; Panayiotou, C. *Polym Eng Sci* 2004, 38, 954.
6. Rutkowska, M.; Heimowska, A.; Krasowska, K.; Janik, H. *Polish J Environ Studies* 2002, 11, 267.
7. George, E. R.; Sullivan, T. M.; Park, E. H. *Polym Eng Sci* 1994, 34, 17.
8. Bikiaris, D.; Panayiotou, C. *J Appl Polym Sci* 1998, 70, 1521.
9. Bikiaris, D.; Prinos, J.; Koutsopoulos, K.; Vouroutzis, N.; Pavlidou, E.; Frangis, N.; Panayiotou, C. *Polym Degrad Stab* 1998, 59, 287.
10. Cardoso E. C. L.; Lugão, A. B.; Andrade, E.; Silva, L. G. *Radiat Phys Chem* 1998, 52, 197.
11. Park, C. P. In *Handbook of Polymeric Foams and Foam Technology*; Klempner, D; Frisch, K. C., Eds.; Hanser: Munich, 1991; p 187.
12. Chandra, R.; Rustgi, R. *Polym Degrad Stab* 1997, 56, 185.
13. Prinos, J.; Bikiaris, D.; Theologidis, S.; Panayiotou, C. *Polym Degrad Stab* 1998, 38, 954.
14. Vasile, C.; Rusu, M. In *Handbook of Polyolefins*, 2nd ed.; Vasile, C., Ed.; Marcel Dekker: New York, 2000; Chapter 21.
15. Baldwin, D. F.; Park, C. B.; Suth, N. P. *Polym Eng Sci* 1996, 36, 1437.