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Effects of electron beam irradiations on the structure and mechanical properties of polycarbonate

J. Chen[a,*], M. Czayka[a], Roberto M. Uribe[b]

[a]*School of Technology, Kent State University—Ashtabula, 43 Street, Ashtabula, OH 44001, USA*
[b]*Program on Electron Beam Technology, Kent State University, P. O. Box 1028 Middlefield, OH 44062, USA*

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Abstract

Structure and mechanical properties of polycarbonate (PC) were investigated with varied electron beam processing parameters such as dose, dose rate and dose fractionation. PC showed noticeable decrease in ductility after doses of 100 kGy; a decrease in tensile strength is relatively minor. Molecular weight degradation was also noticed after 100 kGy. At 150 kGy and high dose rate (21 kGy/s), the tensile strength and ductility were evaluated against dose fractionation. It was found that tensile strength and ductility decreased with increasing number of passes, which resulted from longer cooling off times. The same temperature effect was observed with lower dose rate (1.2 kGy/s) when mechanical properties of irradiated samples were decreased significantly compared with samples irradiated with higher dose rate. No significant variation in molecular weight change was noticed in both cases.

Keywords: Polycarbonate (PC); Mechanical properties; Electron beam irradiation

1. Introduction

Electron beams have been used to process polymers for enhancing mechanical, chemical and other properties (Singh and Silveman, 1992). Radiation-processed products that are now in wide use include wires and cables with cross-linked insulation, components of tires, and medical products. One of the most important process requirements is the absorbed dose in the irradiated material. The required dose is obtained by controlling dose rate (beam current) and conveyor speed. The recent developments in electron beam accelerators allow the machines to produce much higher beam current, and consequently beam heating of the processed material is inevitable. Some high-dose processes require continuous product cooling or multiple passes under the beam to provide time for heat dissipation. In this respect, very limited work has been done related to the effects of the combination of processing parameters on the mechanical properties of irradiated polymers.

When the total dose needs to be applied through several passes, there is considerable time in between for the sample to cool down. Therefore using different conveyor speeds and number of passes to obtain the same total dose, might result in differences in structural changes or properties in the irradiated polymer since they are irradiated at different temperatures. Temperature dependence of radiation degradation or cross-linking was observed by earlier studies for polymers such as polytetrafluoroethylene (PTFE) and polystyrene (PS) (Oshima et al., 1995; Takashika et al., 1999). PTFE was found to have degradation via chain scission and

*Corresponding author. Tel.: +1 440 964 4311; fax: +1 440 964 4269.
E-mail address: chen@ashtabula.kent.edu (J. Chen).

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cross-links at high temperature above the melting temperature. Seguchi et al. (2002) have studied properties of polycarbonate (PC) and polysulfone (PSF) under different temperatures up to its glass transitional temperature. They reported that the hardness could be well controlled by the selection of dose and temperature.

This work reports some results on the mechanical properties of PC when irradiated at different processing parameters such as dose, dose rate as well as number of passes under the beam. It has been reported by Acierno et al. (1980, 1981), that cross-linking predominates at small doses and main chain scission happens at higher doses. The radiation-induced chain scission was also reported by different authors (Rivaton et al., 1983, Kalkar et al., 1992). Kudon et al. (1996) compared high dose rate pulsed electron beam (4.2E10 Gy/s) results with data obtained from gamma irradiation at a low dose rate (0.51 Gy/s). They found no dose rate effects on scission probabilities of PC based on molecular weight measurements. In this study, we used electron beam operated under two different beam currents to achieve different dose rates. The range of dose rates in this study is much smaller than other studies, which used two different irradiation sources. Mechanical properties such as tensile strength and elongation at break as well as molecular weight changes were evaluated.

2. Experimental

The sample material was lexan© PC manufactured by GE. Rectangular shape samples were cut with dimensions 17.5 cm × 40.0 cm × 3.2 mm thick. The panels were irradiated at the Kent State University's NEO Beam facility. The facility houses a 150 kW electron beam accelerator and a radiation dosimetry laboratory. The samples were exposed to a 2 MeV electron beam. The beam length is 7.5 cm and the beam is scanned over a width of 1.2 m. Dosimetry was performed using Far West Technology, FWT-60-00 radiochromic dye film as described in ASTM E 1275-98.

Three experiments were performed with different sample panels. In the first one, a group of samples was irradiated to different dose values by varying the number of passes that the samples were sent under the beam. The beam current was kept constant to a value of 36 mA beam current, yielding a dose rate of about 22 kGy/s. The conveyor speed was set to 9.1 m/min (30 ft/min). The samples were irradiated for 1, 2, 4, 6, and 8 passes under the beam corresponding to doses of 25, 50, 100, 150 and 200 kGy, respectively.

In the second experiment, the effect of fractionated dose was studied. To do this, a group of samples was irradiated at the following conveyor speeds: 1.5, 3.0, 4.6, 6.1, 9.1 and 12.2 m/min (5, 10, 15, 20, 30, 40 ft/min), and the dose was kept constant at 150 kGy, by going through the beam 1, 2, 3, 4, 6 and 8 times. The time between exposures varied from 2 to 10 min depending on the conveyor speed.

In a third experiment, sample panels were irradiated to the same dose (150 kGy) but at two different dose rates, 22 and 1.2 kGy/s. This was accomplished by using two beam currents, 36 and 2 mA. The conveyor speed for the high dose rate was 1.5 m/min (5 ft/min) and the samples were irradiated for a single pass under the beam. In the lower dose rate case, the sample panels had to be irradiated for a total of 17 passes. However, samples were irradiated in a linear motion system (Korwin et al., 2000) which limited the time between exposures to about 20 s.

After the irradiation, the samples were characterized using the following techniques. The first characterization technique consisted of the evaluation of tensile strength and elongation at break for each set of irradiation conditions. Irradiated panels from each group were machined using a CNC mill programmed to cut tensile samples according to ASTM 638. The tensile machine used in this study was an Instron/Saytex T Series with a 25 kN load cell. Samples were placed between the jaws and a load was applied at a rate of 2.54 cm/min until failure occurred. The strain was measured using the cross-head travel measured by the machine. Five samples were used and results were averaged for each data point.

The second characterization technique consisted in the determination of the glass transition temperature (T_g) for each set of irradiation conditions. This was accomplished using differential scanning calorimetry (DSC). The instrument used to conduct these evaluations was a TA Q100 DSC. Samples were prepared by slicing sections of unstressed tensile samples used in the tensile tests. The samples measured approximately 3 mm × 3 mm × 1 mm thick. The mass of each sample was between 6 and 10 mg. Each sample was placed in a standard cup and covered with a lid and roll crimped. Samples were heated at a rate of 15 °C/min under nitrogen. The T_g for each sample was determined using the output data and TA's built in software.

The third method employed to characterize each irradiation condition was to measure the apparent viscosity of the samples at elevated temperature. The instrument used was a Monsanto MPT Processability Tester. Samples were prepared by shearing approximately 5 mm × 5 mm pellets from unstressed material leftover from the two previous test methods. Ten grams of pellets were added to the heated cylinder of the MPT. Samples were held in the cylinder for 10 min to allow them to reach the cylinder temperature. The instrument was then activated to start the test. The instrument was programmed to push a heated piston through the cylinder at a rate of 2.54 cm/min. The material was extruded through a die with an L/D ratio of 20. The