Photodegradable Polymer Degradation Analysis Using the EcoSEC® GPC System

EcoSEC GPC System
APPLICATION NOTE

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Introduction

Photoresponsive polymers have several advantages over other stimuli responsive materials due to the spatial and temporal control of the input.[1] Photoactivation can be used to influence various polymer properties such as release or capture of additives, change in viscosity, modulus and pH. Early efforts in the field of photoresponsive polymers were aimed primarily at decreasing the environmental impact of plastics in landfills and on marine life. However, the long degradation time and non-biodegradability of these materials make them unsuitable for biological applications. Currently there is a strong need in biomedical applications for polymers that are both photodegradable and biodegradable. Such polymers are being investigated as drug delivery devices and as platforms with phototunable physical and mechanical properties.

To address the needs of biological application, we have developed a new class of photodegradable polycarbonate materials based on the alkoxyphenacyl photoactive moiety that undergo controlled degradation to oligomers upon irradiation at 300 nm.[1] These polycarbonates are mechanically robust, biodegradable, and stable at high temperatures in the absence of light. The combination of the thermal and mechanical properties of these polymers promises usefulness in biomedical applications such as controlled drug release devices, ocular implants, and dermal patches.

The photodegradable polycarbonate homopolymer as well as different copolymers with poly(ethylene glycol) (PEG) were synthesized and characterized by gel permeation chromatography (GPC) using the EcoSEC GPC System. Here we report, through molar mass averages and polydispersity index values as determined by GPC, the photodegradation of the polycarbonate homopolymer, 5% PEG copolymer, and 10% PEG copolymer by irradiation of the polymers in chloroform in a Rayonet reactor at 300 nm as well as the hydrolytic degradation of the copolymers by incubation in phosphate buffered saline (PBS) at 37 °C.

Experimental Conditions

Sample analysis of the homopolymer, copolymers, photodegraded samples, and hydrolytically degraded samples were performed on a system consisting of an EcoSEC GPC System (HLC-8320) equipped with a dual flow refractive index detector (RI) and UV detector. The polymers under investigation have UV absorption from 250 to 320 nm with a λ_{max} at 280 nm. Separation of injections occurred over a column bank consisting of two 6 mm ID × 15 cm, 3 µm particle size TSKgel® SuperH3000 (exclusion limit 6 × 10^4 g/mol) and one 6 mm ID × 15 cm, 3 µm particle size TSKgel SuperH4000 (exclusion limit 5 × 10^5 g/mol) columns (Tosoh Bioscience LLC). The mobile phase and solvent were chloroform ($CHCl_3$) (HPLC grade, EMD Omnisolv®) at flow rate of 0.38 mL/min. Detector, pump oven, and column oven were maintained at 40 °C. For all chromatographic determinations, results are those based on a polystyrene calibration curve. Data was processed with the EcoSEC GPC Workstation Software version 1.08.

Polymer chain photodegradation with time of irradiation

The photodegradable homopolymer poly(2-hydroxy-1-(4-(3-hydroxypropoxy) phenyl) ethanone carbonate) (20 mg) was dissolved in chloroform and transferred to a quartz tube. The quartz tube was sealed with a rubber septum and irradiated in a Rayonet RPR-200 reactor at 300 nm where the polymer has a significant UV absorption (5.34 mW/cm2). Every 5 minutes, the reactor was turned off and 1 mL of reaction mixture was taken out and filtered through a 0.45 µm PTFE filter. A total of 9 samples were taken in 40 minutes of irradiation and the rest of the solution was irradiated for an extra hour.

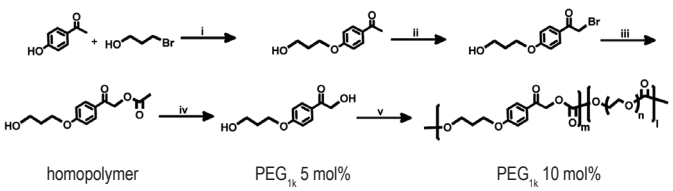
Hydrolytic degradation of polymers

Poly(2-hydroxy-1-(4-(3-hydroxypropoxy)phenyl)ethanonecarbonate)-*co*-poly((poly(ethylene glycol) diol) carbonate) copolymers were dissolved in $CHCl_3$. The solution was stirred for a few hours to allow the polymer to dissolve in the solvent completely. Polymer films were prepared by solvent casting the above solution into a Teflon® dish and allowing the solvent to evaporate slowly overnight and were dried under vacuum prior to use. Hydrolytic degradation was monitored by immersing half of each polymer film (~36 mg) in a vial containing 5 mL of PBS solution in an incubator at 37 °C. At the end of every week (total of 4 weeks) a small piece of film was taken from the vial, dried, dissolved in $CHCl_3$ and analyzed by GPC.

Results and Discussion

Polycarbonate homopolymer and copolymers were synthesized using the scheme shown in *Figure 1*. After synthesis the polystyrene relative molar mass averages, M_n and M_w, and the polydispersity index, *PDI*, were determined using the EcoSEC GPC System encompassing a dual flow refractive index detector and a UV detector. Three polymers were synthesized and analyzed; an alkoxyphenacyl-based polycarbonate homopolymer, 5% PEG copolymer, and 10% PEG copolymer. The polystyrene relative molar mass averages, M_n and M_w, and the polydispersity index, PDI, for the initial homopolymer and copolymers are given in *Table 1*. The polystyrene weight-average molar mass values were also determined for the homopolymer and copolymers after photochemical degradation and hydrolytic degradation.

Figure 1. Synthesis of photodegradable polymers[1]



a(i) K_2CO_3/18-crown-6, acetone reflux. (ii) $CuBr_2$, EtOH, $CHCl_3$ (over two steps: 75% yield). (iii) NaOAc, CH_3COOH, H_2O (99% yield). (iv) 1. NaOH, MeOH, 2. $NaHSO_4$ (46% yield). (v) Triphosgene, $CHCl_3$, pyridine, PEG_{1k}

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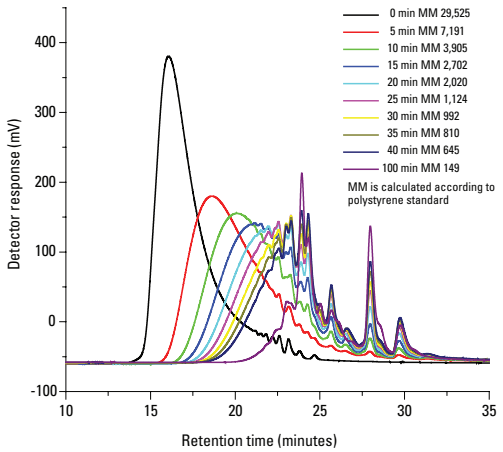
Table 1. Molar mass distributions and polydispersity index for homopolymer and copolymers

Composition	M_n (g/mol)	M_w (g/mol)	PDI
Homopolymer	1.29×10^4	2.95×10^4	2.3
5% PEG	2.27×10^4	2.63×10^4	1.2
10% PEG	8,810	1.04×10^4	1.2

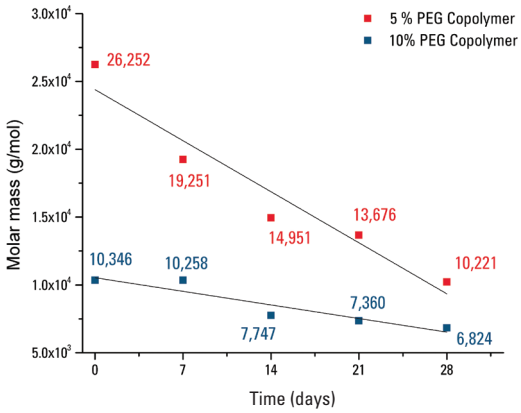
The photochemical degradation of the homopolymer and copolymers was examined by irradiation in $CHCl_3$ in a Rayonet reactor at 300 nm. GPC elution profiles of the irradiated samples of the homopolymer showed that the polymer underwent controlled time-dependent chain scissions upon irradiation, *Figure 2*. Prior to irradiation the polystyrene relative weight-average molar mass of the homopolymer was determined to be 2.95×10^4 g/mol. Within five minutes of irradiation of the homopolymer, there was a loss of three-fourths of the weight-average molar mass, M_w, of the polymer, $M_w = 7.2 \times 10^3$ g/mol. After a hundred minutes of irradiation of the homopolymer the weight-average molar mass, M_w, of the polymer had decreased to 146 g/mol. The weight-average molar mass values were shown to continuously decrease with increasing irradiation time. Along with a decrease in the weight-average molar mass a decrease in polymeric size was also observed, as the GPC elution profile shifts towards longer retention times with increasing irradiation time. The longer retention time of the irradiated homopolymer is an indication that the irradiated homopolymer is smaller in polymer size compared to the non-irradiated homopolymer: as elution order in GPC is that of an "inversing-sieving" technique, smaller analytes elute after the larger analytes. The photodegradation of the copolymer polymers showed a similar trend to that of the homopolymer.

Figure 2. GPC elution profiles showing decrease in weight-average molar mass, M_w, with increasing irradiation time for the polycarbonate homopolymer.



Hydrolytic degradation of the polymers was obtained by incubation of the copolymers, 5% and 10% PEG, in phosphate buffered saline at 37 °C. For the copolymers, hydrolytic degradation is reflected by the molar mass loss with the time of incubation, *Figure 3*. For example, over a period of 28 days, the copolymer with 5% PEG showed increasing molar mass loss with time and ultimate loss of 61% of molar mass on day 28. As expected, the photochemical degradation is much faster – the polymer undergoes almost complete photodegradation within 30 minutes, *Figure 2*, while hydrolytic degradation over 28 days results in a 61% loss for the 5% PEG copolymer, *Figure 3*.

Figure 3. Hydrolytic degradation of copolymers reflected by the molar mass loss with the time of incubation.



Conclusions

The synthesis and properties of a new class of photodegradable polymers that undergo controlled chain scission upon irradiation at 300 nm were analyzed using the EcoSEC GPC System. The polystyrene relative molar mass averages of a homopolymer and two copolymers were determined before, during and after photochemical and hydrolytic degradation. Additionally, the GPC elution profile was monitored during both photodegradation processes. The photodegradation results demonstrate that the polymers quickly lose their molar mass upon irradiation. These properties along with others determined via different characterization methods, *e.g.* NMR, make these polycarbonate homopolymer and copolymers valuable for many biomedical applications.[1] The low dispersion design of the EcoSEC GPC System combined with the use of 15 cm long TSKgel columns provided a fast and robust method for monitoring the degradation of the homopolymer and copolymers by GPC.

References

[1]Sun, S.; Chamsaz, E.A.; Joy A. Macro Lett., **2012** 1 (10), 1184-1188
[2]Givens, R. S.; Heger, D.; Hellrung, B.; Kamdzhilov, Y.; Mac, M.; Conrad, P. G.; Cope, E.; Lee, J. I.; Mata-Segreda, J. F.; Schowen, R. L.; Wirz, J. J. Am. Chem. Soc. **2008**, 130, 3307-3309.

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