

Synthesis and characterization of biodegradable polyurethanes: influence of the structure and functionalities (OH groups) of the polyester macromonomer.

H. Sandoval-Escobar ¹, F. Díaz-Camacho ¹, A. Martínez-Richa ¹⁺

¹ Facultad de Química, Universidad de Guanajuato, Noria Alta S/N, 36050, Guanajuato, Gto., Mexico

richa@quijote.ugto.mx¹⁺

Introduction

Polyurethanes have become important biomedical materials. Some applications in the biomedical area are: a) temporary scaffolds to facilitate tissue regeneration, and b) matrices for control drug release [1-2]. For biomedical applications, a biodegradable material is desirable. Linear polyurethanes can be conveniently prepared from the reaction between diols and diisocyanates. The macromonomer diols derived from ϵ -caprolactone (CL) has been used to obtain polyurethanes with biodegradable properties [3-5]

α - ω -telechelic poly (ϵ -caprolactone) derivatives are usually prepared by ring opening polymerization (ROP) of ϵ -caprolactone, using an initiator/chain transfer agent (a functional low molecular weight molecule) and catalyst [6].

In this work, we report synthetic routes to obtain α -hydroxylic- ω -dodecyl amide poly(ϵ -caprolactone) (DodNH-PCL), and α -hydroxylic- ω -tris(1,3-diamide-2-hydroxy-propane) poly(ϵ -caprolactone) (trisO-PCL) by ROP of CL using dodecylamine and 1,3-diamino-2-hydroxy-propane as initiators, respectively. Decamolybdate anion or tin(II)-2-ethylhexanoate were used as catalyst. An CL/catalyst molar ratio of 5000, 10000, 20000 and 40000 were used for decamolybdate anion and 1250, 2500 and 5000 for tin(II)-2-ethylhexanoate. The obtained number-average molecular weight M_n for DodNH-PCL and trisO-PCL (M_n of arm) were 530, 1250, 2000 and 25000 g/mol. These derivatives were successfully used to prepare poly(ester-urethane) copolymers, by reaction with 1,6-diisocyanatohexane and di(ethylene glycol).

Experimental conditions.

Materials. ϵ -caprolactone (Sigma-Aldrich) was dried over calcium hydride and distilled under vacuum before use. Dodecylamine (Fluka) and 1,3-diamino-2-hydroxy-propane (Sigma-Aldrich) were used as received. Ammonium heptamolybdate tetrahydrate $(\text{NH}_4)_6[\text{Mo}_7\text{O}_{24}]\cdot 4\text{H}_2\text{O}$ (Fluka) was grounded in a mortar and passed through a 100 mesh sieve. The grounded catalyst was dried in an oven at 80°C overnight before use. Tin(II)-2-ethylhexanoate (catalyst), 1,6-diisocyanate-hexane and di(ethylene glycol) monomers (Sigma-Aldrich) were used as received.

Synthesis

α -hydroxylic- ω -dodecyl amide poly(ϵ -caprolactone) (DodNH-PCL). All experiments were carried out in glass vials. In a typical experiment 1 mL of CL (1.03g, 9.024mmol), dodecylamine (0.5539g, 2.98mmol for DodNH-PCL of 530g/mol; 0.1793g, 0.97mmol for DodNH-PCL of 1250 g/mol; 0.1052g, 0.57mmol for DodNH-PCL of 2000 g/mol and 0.0077g, 0.04mmol for DodNH-PCL of 25000 g/mol) and catalyst (0.0006g, 0.0005mmol for Ammonium heptamolybdate tetrahydrate $(\text{NH}_4)_6[\text{Mo}_7\text{O}_{24}]\cdot 4\text{H}_2\text{O}$ or 0.0029g, 0.0072mmol for Tin(II)-2-ethylhexanoate) were placed in glass vials. The vials were stoppered at room temperature and placed in thermostated baths at 120°C and 150°C. Vials were removed from the baths at different reaction times (1, 2, 4, 6, 8, 10 and 24 hours). No inert atmosphere was used. The obtained polymers (DodNH-PCL) were characterized by ^1H and ^{13}C NMR, and MALDI-TOF.

α -hydroxylic- ω -tris(1,3-diamino-2-hydroxy-propane) poly(ϵ -caprolactone) (trisO-PCL): In a typical run, 1 mL of CL (1.03g, 9.024mmol), 1,3-diamino-2-hydroxy-propane (0.0703g, 0.7804mmol for PCL triol of 530g/mol; 0.0267g, 0.2960mmol for PCL triol of 1250 g/mol; 0.0162g, 0.1797mmol for PCL triol of 2000 g/mol and 0.0012g, 0.0138mmol for PCL triol of 25000 g/mol) and catalyst (ammonium decamolybdate or Tin(II)-2-ethylhexanoate) were placed in glass vials. Molar ratios CL/catalyst were 5000, 10000, 20000, and 40000 for $(\text{NH}_4)_8[\text{Mo}_{10}\text{O}_{34}]$ and 1250, 2500 and 5000 for Tin(II)-2-ethylhexanoate. The vials were stoppered at room temperature and placed in two thermostated baths at 120°C and 150°C. Vials were removed from the baths at different reaction times (1, 2, 4, 6, 8, 10 and 24 hours). No inert atmosphere was used. The obtained polymers were characterized by ^1H and ^{13}C NMR, and MALDI-TOF.

Synthesis of polyurethanes. The copolymers were obtained in two steps. In the first step 1g of DodNH-PCL or trisO-PCL (0.80mmol for the PCL of 1250 g/mol), 1,6-diisocyanate-hexane (135 μ L, 0.84mmol for the PCL of 1250 g/mol), catalyst (Tin(II)-2-ethylhexanoate) (2.6 μ L, 0.008mmol for the PCL of 1250 g/mol), and 3mL of CH₃Cl were placed in a glass vial. Reaction mixture was stirred until homogenization. The vial was stoppered at room temperature and placed in a thermostated bath at 80°C. Vial was removed from the bath after 3 hours of reaction by testing the decay of the signal peak of the di-isocyanate in FTIR (at 2250-2280 cm⁻¹) at approximately the half. In the second step of the reaction, 1,6-diisocyanate-hexane (675 μ L, 4.2mmol for the PCL of 1250 g/mol), di(ethylene glycol) (380 μ L, 4.0mmol for the PCL of 1250 g/mol), and 3 mL of CH₃Cl were added to the mixture of reaction. The vial was stoppered and placed again in a thermostated bath at 80°C. Vial was removed from the bath after 3 hours of reaction by testing the disappearance of the signal peak of the di-isocyanate in FTIR (at 2250-2280 cm⁻¹). Polyurethane films were obtained by casting in a leveled glass within a fume cupboard. The cast solution was placed in a box to protect it from dust and allowed to stand at ambient temperature for 24 hours. The film was then released. Samples for physical characterization were cut in small pieces from films. Film thickness ranged from 50-250 μ m.

Results and discussion.

Figure 1 shows the kinetics curves obtained for α -hydroxylic- ω -dodecyl amide poly(ϵ -caprolactone) (DodNH-PCL) with Mn = 1250 g/mol. In all curves when catalyst concentration increased the polymerization rate increased too. The catalyst used was ammonium decamolybdate (NH₄)₈[Mo₁₀O₃₄] and the ideal concentration was found at molar ratio CL/catalyst=20000.

Results obtained in the preparation of trisO-PCL are shown in figure 2. The same behavior observed in the preparation of DodNH-PCL was observed.

The same procedure was followed for the preparation of samples with Mn = 530, 2000 and 25000 g/mol. Polyurethanes formation was followed by FTIR. Polymers structure were confirmed by ¹³C RMN

Conclusions

DodNH-PCL and trisO-PCL of $M_n = 530, 1250, 2000$ and 25000 g/mol, were prepared by ROP of CL. Dodecylamine and 1,3-diamino-2-hydroxy-propane initiators were successfully inserted into the PCL chains. Ammonium decamolybdate is better catalyst than tin(II)-2-ethylhexanoate, because a lower molar ratio of CL/catalyst=20000 was necessary to obtain high conversions in

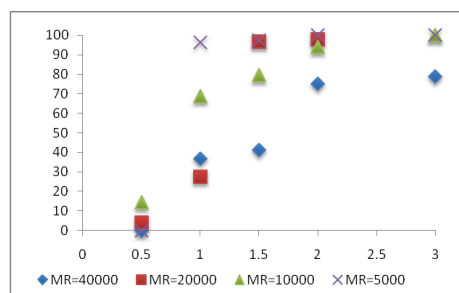


Figure 1. Kinetic curves for the preparation of α -hydroxylic- ω -dodecyl amide poly(ϵ -caprolactone) of 1250g/mol.

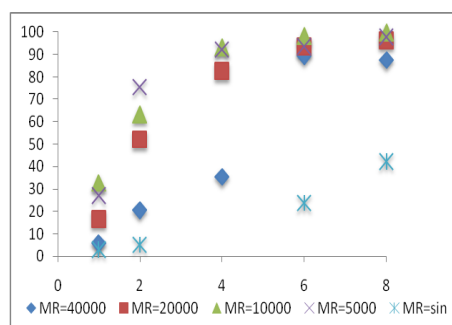


Figure 2. Kinetic curves for the preparation of α -hydroxylic- ω -tris(1,3-diamide-2-hydroxy-propane) poly(ϵ -caprolactone) the 1250 g/mol PCL tri-ol

shorter reaction times. The DodNH-PCL and trisO-PCL structures were verified by ^{13}C NMR. Obtained PCLs were used as macromonomers to obtain poly(ester)-co-poly(urethane) copolymers, keeping the molar ratio of PCL/1,6-diisocyanate hexane/di(ethylene glycol) at 1.0/6.0/5.0. Crystalline degree, mechanical properties and biodegradability behavior are under evaluation.

References.

BIO-P

- [1] Lelah MD, Cooper SL, editors, Polyurethanes in medicine, Boca Raton, FL; CRC Press, 1986
- [2] Chasin M, Langer R, editors, Biodegradable polymers as drug delivery systems, New York, Marcel Dekker, 1990
- [3] Lefevre C, Tidjani A, Vander C, David C., J. Appl Polym Sci, 2002, 83, 1334
- [4] Heijkants RG, Schwab LW, van Calck RV, de Groot JH, Pennings AJ, Schouten AJ, Polymer, 2005, 46, 8981
- [5] Marcos-Fernández A, Abraham GA, Valentín JL, San Román J, Polymer, 2006, 47, 785
- [6] Báez E, Marcos-Fernández A, Lebrón-Aguilar R, Martínez-Richa A, Polymer, 2006, 47, 8420