STUDIA UBB CHEMIA, LVI, 2, 2011 (p. 57 - 63)

SYNTHESIS OF POLY(L-LACTIC ACID) BY DIRECT POLYCONDENSATION

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ABSTRACT. Poy (lactic acid), a biodegradable polymer, has been extensively studied during last 15 years due to its wide range of applications. In this study, the synthesis of the poly (L-lactic) acid) with appropriate molecular weight for medical applications was investigated. Stanous(II) chloride was used as catalyst in a quantity of 0.25 wt% calculated on the monomer. Polycondensation was carried out over a period of 72 h, using xylene as solvent. The identification and purity of the obtained polymer was assessed by NMR spectroscopy. The molecular weight of PLA was measured by the intrinsic viscosity method.

Keywords: *lactic acid, catalysis, direct polycondensation.*

INTRODUCTION

Large amounts of plastics are fabricated worldwide and the removal of plastics after use is becoming a serious problem. To overcome these environmental problems, several types of biodegradable polymers have been studied: poly(butylenesuccinate), poly(3-hydroxybutyrate-co-3-hydroxyvalerate) and polycaprolactone, [1]. These polymers are degradable in soil, water or compost, but they exhibit low transparency and reduced mold resistance. Polylactic acid (PLA) has been recognized as having an excellent potential for biodegradable packaging and consumer goods because of its properties (mechanical strength, transparency, compostability and safety) [2]. Also, PLA has been used as bioadsorbable material in medical uses and has mold resistance [3]. PLA is degraded by simple hydrolysis of the ester linkage and does not necessitate enzyme to catalyze this process; the degradation rate depend on the isomer ration, the size and form of the product and the temperature of hydrolysis [4].

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PLA is one of the few polymers in which the stereochemistry can be modified by polymerizing a mixture of L- or D-isomers in order to obtain high-molecular-weight crystalline or amorphous polymers [5].

There are two methods to produce polylactic acid from the lactic acid: direct polycondensation (PC) of lactic acid and ring-opening polymerization (ROP) of lactide monomer, which is the cyclic dimer of lactic acid [6]. During the last process water is not produced, so high-molecular-weight PLA can be obtained. However, due to the high process costs of obtaining and purifying lactide, PLA use has been limited only to some medical applications. In comparison with the catalytic ring-opening polymerization of L-lactide [7-9], attaining high-molecular-weight PLA polymers by direct dehydropolycondensation of L-lactic acid is not easy because of various factors: efficient removal of water, a water tolerant catalyst, difficult control of depolymerization and kinetic control [10-13]. The water byproduct formed by reaction induces reverse reactions that result in the hydrolysis of the ester linkages. If the temperature for reaction is too high, the rate of depolymerization becomes higher than the rate of polymerization [14, 15].

The aim of this work was to obtain poly(L-lactic) acid with appropriate-molecular weight and high-purity degree that makes it suitable for medical applications. Therefore, this study is indented to be a contribution to the study of synthesis of high-molecular-weight PLA.

RESULTS AND DISCUSSION

In this polymerization method it is extremely important to reduce efficiently the water content. For this reason, the monomer was distilled by heating at 100°C for 24 h. This process resulted in the formation of dimer and trimer of lactic acid and/or other impurities and this step has a bad effect on molecular weight of PLA. Therefore in this work, we used the monomer without the distillation step.

The removal of dimer and trimer of lactic acid and/or other impurities was performed by adding deionized water to the final solution.

Table 1 show the viscosity-average molecular weight of synthesized PLA.

Table 1. Polycondensation of lactic acid[a]

	Catalyst	Molecular sieve	Time (h)	$\overline{M_v}$
PLA-a	+	-	28+48	11900
PLA-b	-	-	72	8100
PLA-c	+	+	28+48	14400
PLA-d	-	+	72	9300

[a] All reactions were performed by azeotropic distillation technique using xylene at 135°C.

$SnCl_2{\cdot}2H_2O$ was used as catalyst in quantity of 0.25 wt% calculated according to the amount of monomer. A large amount of catalyst accelerated not only the polycondensation method but also the depolymerization [15]. The syntheses were performed with dried solvents during the process and its circulation in the closed system in order to control the equilibrium process of PLA formation: PLA-H_2O and PLA-lactide [16]. It is very important to mention that when temperatures higher than 140 ^{o}C were utilized, severe oxidation was occurred, which were observed by the formation of the dark brown color.

The progress of the polycondensation of L-lactic acid, in solution, was controlled by regular sampling of small amounts from the reaction mixture and determining the viscosity of the isolated PLA.

Generally, tin compounds are frequently used for the synthesis of PLA due to their high catalytic activity and good solubility in organic solvents. Due to inorganic tin compounds are less toxic than organotins and Sn(IV) compounds are less toxic than Sn(II) compounds, inorganic tin catalysts are considered a better choice as a catalyst. A possible mechanism for the catalytic activity of the stannous compounds is reported by Kim *et al.* [17].

Figure 1 shows the effect of $SnCl_2{\cdot}2H_2O$ on the viscosity-average molecular weight of PLA. $SnCl_2{\cdot}2H_2O$ has a good activity and the $\overline{M_v}$ of synthesized PLA was about 11900. This value is considerable higher than that of PLA synthesized without using $SnCl_2{\cdot}2H_2O$.

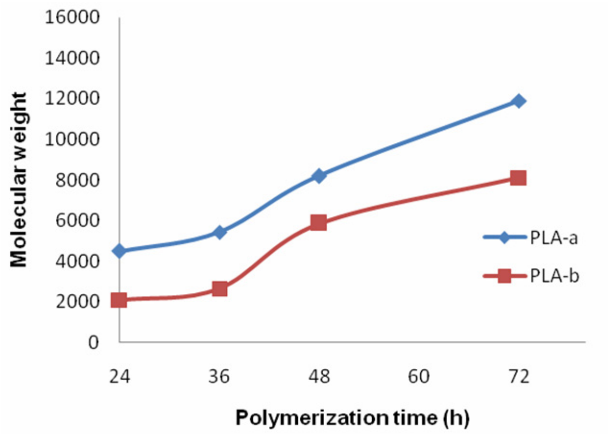

Figure 1. The effect of $SnCl_2{\cdot}2H_2O$ on the viscosity-average molecular weight of PLA synthesized by direct polycondensation method: (PLA-a) using $SnCl_2{\cdot}2H_2O$; (PLA-b) without using $SnCl_2{\cdot}2H_2O$.

No significant increase in the viscosity-average molecular weight of PLA was observed when molecular sieve were used. The molecular weight of PLA, without using molecular sieve was about 8100 and about 9300 using molecular sieve, respectively (Figure 2). This is due to the irreversible process in which the molecular sieve are saturated as polymerization progress even though this is the most effective drying agent to reduce the dissolved water content in organic solvent.

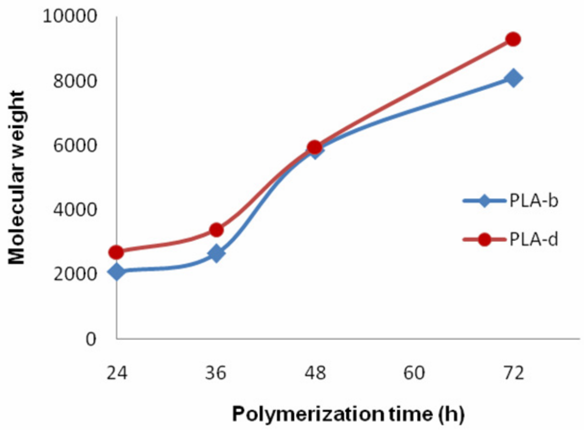

Figure 2. The effect of molecular sieve on the on the viscosity-average molecular weight of PLA synthesized by direct polycondensation method: (PLA-b) without using molecular sieve; (PLA-d) using molecular sieve.

Significant higher viscosity-average molecular weight of PLA ($\overline{M_v}$ =14400) was obtained when it was used both $SnCl_2 \cdot 2H_2O$ and molecular sieves (PLA-c).

The longer polymerization time, the higher viscosity-average molecular weight of PLA was obtained due to the high activation energy of polycondensation [15].

The IR spectra of PLA-c exhibited similar characteristic absorption peaks of ester (at 1760 and 1090 cm^{-1} for –COO- and –O-) and $-CH_2$- and $-CH_3$ groups (at 2950-3020 cm^{-1}). The characteristic absorption peaks of hydroxyl group of PLA were not observed proving that a high molecular weight PLA was obtained.

The ^1H NMR recorded spectra of the obtained crystals were similar and confirm the synthesis of PLA and demonstrate its purity. The ^1H NMR spectra of synthetized PLA were similar and exhibited the signal of methyl group at 1.68 ppm, the signal of the methyl next to alcoxy group at 3.50 ppm and the signal of methine group at 5.05 ppm. The signal of hydroxyl hydrogen of carboxyl group disappeared in the ^1H NMR spectra.

The above results were in perfect agreement with those of an authorized PLA specimen.

This kind of polymers may be useful in biomedical applications.

CONCLUSIONS

PLA was synthesized by direct polycondensation using a reactor equipped with a Dean-Stark trap in order to separate the water by-product. The highest viscosity-average molecular weight of PLA was about 14400 when $SnCl_2 \cdot 2\ H_2O$ and molecular sieve were used. Molecular sieve were used as drying agent to reduce the small amount of water in the organic solvent. These findings suggest that the method using molecular sieve could be recommended for the preparation of PLA. The molecular weight of PLA increases with the polymerization time. The temperature of the synthesis of PLA should not exceed 140 ^oC because at higher temperatures racemization can occur. The obtained PLA could be used for different medical applications.

The direct polycondensation process presented above can be applied to the synthesis of other hydroxyacids.

EXPERIMENTAL SECTION

All chemicals were purchased from Merck. All the solvent were dried over molecular sieves (3 Å) prior use. Molecular sieves were dried at 250 ^oC before use. Other chemicals were used as received. L-lactic acid was a 85-90 % (w/w) aqueous solution of monomer, 99% optically pure according to the manufacturer. Deionized water was obtained using a Milli-Q system (Millipore, Watford, Hertfordshire, UK).

The ^1H NMR spectra for the identification and purity degree of PLA were recorded on a Bruker DRX 500-MHz NMR Spectrometer; the samples were dissolved in $CDCl_3$, at room temperature. The sample concentration was about 10% by weight.

FTIR spectra were recorded using a FT-IR Spectrum BX II Perkin Elmer Spectrometer.

The molecular weight of PLA was determined by viscosimetry, using Ubbelhode capillary viscometers places in a water-bath thermostatically controlled at 30 ^oC. PLA was dissolved in chloroform (0,2 g/dl). The viscosity-average molecular weight of PLA was calculated according to the following equations [18]:

$$[\eta] = \frac{\sqrt{2(\eta_{sp} - \ln \eta_{r})}}{C} \qquad (1)$$

where

$\eta_{sp} = \eta_r - 1$ and $\eta_r = t/t_o$, η_{sp} – the specific viscosity, η_r – the relative viscosity, C – the concentration of polymer (g/dL) and

$$[\eta] = 1.25\times 10^{-4}\overline{M}_w^{\,0.717} \tag{2}$$

where

[η] – the intrinsic viscosity.

Synthesis of PLA by direct dehydropolycondensation

Two different polymerization methods were carried out: (a) azeotropic dehydratation at 140 °C for 72 h without using molecular sieve as dying agent and (b) azeotropic dehydratation at 140 °C for (24 + 48) h using molecular sieve as dying agent. The catalyst can be recovered after filtration and reused.

(a) Tin-catalyzed synthesis of PLA by direct dehydropolycondensation without using molecular sieve

Using a 250 mL reaction vessel equipped with a Dean-Stark trap, 20.1 g of 85-90 % L-lactic acid was azeotropically dehydrated using 100 mL xylene for 72 h at 140 °C, in the presence of $SnCl_2$ 2 H_2O (0.2 wt.-%) as catalyst. The reaction mixture was cooled to room temperature and concentrated to about fourth-volume. 100 mL dichloromethane was slowly added and the catalyst was removed by filtration. The dissolved polymer was precipitated by addition of water and the solvent evaporation was allowed for 24 h at room temperature, maintaining the solution under stirring, thus dry solid polymer (PLA-a) was isolated.

(b) Non-catalyzed synthesis of PLA by direct dehydropolycondensation without using molecular sieve

Similar polymerization method was performed without using catalyst resulting PLA-b.

(c) Tin-catalyzed synthesis of PLA by direct dehydropolycondensation using molecular sieve

Using a 250 mL reaction vessel equipped with a Dean-Stark trap, 20.1 g of 85-90 % L-lactic acid was azeotropically dehydrated using 100 mL xylene for 24 h at 140 °C, in the presence of $SnCl_2 \cdot 2\,H_2O$ (0.2 wt.-%) as catalyst. After the removal of water in the Dean-Stark trap, the reaction vessel was cooled to room temperature and in the place of Dean-Stark trap was mounted a tube completely packed with molecular sieve (3 Å). The refluxing solvent is returned to the vessel by way of the molecular sieves for an additional 48 h at 140 °C. After the reaction mixture was concentrated to about fourth of the volume, the following steps were the same as for the above-mentioned polymerization methods resulting PLA-c.

(d) Non-catalyzed synthesis of PLA by direct dehydropolycondensation using molecular sieve

Similar polymerization method was performed without using catalyst to obtain PLA-d.

ACKNOWLEDGMENTS

The authors are grateful to CNMP-Romania for supporting the project PNII-72152/2008 - BIOPLAST.

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