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Research Article

CHEMISTRY

Synthesis and characterization of poly L-Lactic acid by direct polycondensation

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ABSTRACT

Significant scientific and engineering efforts have been made in the discovery, development, and application of polymers as a result of social and economic progress. One of the most promising biopolymers is polylactic acid (PLLA), which may be manufactured from nontoxic renewable feedstock. Due to its qualities including biocompatibility, biodegradability, mechanical strength, and processability, PLA has become a crucial polymeric material for biomedical applications. By fermenting sugars sourced from renewable resources like corn and sugarcane, lactic acid (LA) can be produced. Thus, PLLA is a non-toxic, eco-friendly polymer with properties that allow for usage in the human body.

Due to its compatibility and biodegradability, poly L-lactic acid (PLLA) has attracted considerable interest from the scientific community. For PLLA, there are several uses. Direct polycondensation was used to create PLLA, along with a variety of catalysts and coupling agents. By using FT-IR spectroscopy, viscosity to determine molecular weight, acid value, and Thermal Gravimetric Analysis. The generated PLLA was identified.

Introduction

Biodegradable polymers are widely used in tissue engineering applications as well as in biomedical devices. There are two types of biodegradable polymers: natural and synthetic. Synthetic polymers provide several benefits over naturally occurring materials. A process that can be repeated to make the same polymer with the same composition every time can be used to create synthetic polymers (Li *et al.*, 2020). According to the application, they can be created with a huge variety of physical, chemical, and mechanical qualities. They are also infinitely available (Dhaliwal, 2018).

The polyester family's PolyLactic Acid (PLA), PolyGlycolic Acid (PGA), and its copolymers, such as PGLA, contain the most commonly used synthetic biodegradable polymers (Pillai and Sharma, 2010). They have several applications, including resorbable sutures, surgical fixation devices, and drug administration devices, and have been thoroughly explored and published in the literature.

A hydrophobic polymer known as polylactic acid, sometimes known as poly-hydroxy acids, poly-esters, or

Aliphatic polyesters, is a type of biomaterial. Lactic acid, a water soluble monomer that exists in two enantiomeric forms, L-(+)-LA and D-(-)-LA, is the starting material for the synthesis of PLA. L-(+)-LA is the isomer of interest for biomedical applications even though two enantiomers are used in industrial practise since it is engaged in the cellular metabolism of the human body and lowers the risk of adverse effects. L-(+)-LA can be removed from the body in the form of water and carbon dioxide from the lungs or it can be turned into glycogen in the liver in an *in vivo* setting (Casalini *et al.*, 2019).

The self-esterification of lactic acid, a di-functional monomer, occurs via a reversible step growth mechanism in which polymer chains interact to form longer chains (Ehsani, Khodabakhshi, and Asgari, 2014).

The least expensive process is condensation polymerization, although it is challenging to produce high molecular weights using this approach. To lengthen the chains, coupling or esterification-promoting chemicals must be used (Lopes *et al.*, 2012), yet at the penalty of rising costs and complexity (multistep process). In order to produce long chain polymers,

chain coupling agents must react with either the hydroxyl (OH) or carboxyl end-groups of the PLA (Tuominen *et al.*, 2002).

The current study's objective is to develop a cost-effective method for synthesizing PLLA with various molecular weights employing catalysts and coupling agents.

Experimental

Materials

L (+) lactic acid (assay 88-92%) was purchased from LOBA CHEMIE PVT.LTD (India). Xylene and diethyl ether were bought from Alpha Chemika (India). Decalin and chloroform (assay 99%) were acquired from BIO.CHEM (Egypt) and magnesium oxide from BDH laboratory supplies in Poole, BH151TD (England). Absolute ethyl alcohol (assay 99.9%), Acetone, and Calcium chloride were purchased from BIO.CHEM (Egypt). zinc oxide, maleic anhydride, and zinc chloride were purchased from Alpha Chemika, (India). We bought magnesium chloride from BIO.CHEM (Egypt) and aluminum oxide from RIEDEL-DE HAEN AG SEELZE-HANNOVER (China).

Instrument

FT-IR spectroscopy

Burker, TENSOR 27-series FT-IR, Germany were used in experiments employing KBr pellets at Tanta University's central laboratory to record FT-IR in the 400–4000 cm^{-1} range.

Viscosity

At Tanta University's Polymer Research Group at the Faculty of Science, viscosity was measured using automated viscometer Brookfield Rotational Viscometer Manufacturer, Brookfield Digital Viscometer for Adhesives).

Using a single-point determination, the intrinsic viscosity $[\eta]$ of chloroform ($c=2$ g/dl) at 25 °C was derived as follows: As shown in equation (1), the Solomon-Cuita equation (Moon *et al.*, 2003)

$$[\eta] = \frac{\sqrt{2(\eta_{sp} - \ln \eta_r)}}{c} \quad \text{Equation (1)}$$

Where $\eta_r = t/t_0$, $\eta_{sp} = \eta_r - 1$ are the relative and the specific viscosity, respectively. C is the concentration of PLLA. Additionally, the Mark-Houwink-Sakurada relation was used to compute the viscosity molecular weight (M_v) of PLLA and is shown in equation (Zhang and Wang, 2008)

$$[\eta] = KM^\alpha \quad \text{Equation (2)}$$

K was calculated according to the previously described work in literature (Kaavessina *et al.*, 2016) using values as follows

$$K=1.29 \times 10^{-4}, \alpha=0.82 \text{ (for PLA)}$$

Acid value determination (AV)

In a 250 mL conical flask, 0.2 to 0.5 g of the material was dissolved in 25 mL of acetone. The solution was titrated with 0.1 N alcoholic potassium hydroxide solution using phenolphthalein as an indicator after standing for five minutes. Blank determination was made at the same time without a sample. The acid value is reported as milligrams of potassium hydroxide required to neutralize 1 g sample **equation (3)**.

$$\text{Acid value} = (56.1(A-B) \times N)/W$$

equation (3)

Where A is the amount of KOH solution consumed by the sample (in milliliters), B is the amount consumed by the blank reading (in milliliters), N is the KOH solution's normality, and W is the sample's weight (g) (Kaavessina *et al.*, 2016).

Thermal Gravimetric analysis (TGA)

TGA analysis was carried out to measure change in mass with increase in temperature, thermal stability, and

maximum degradation temperature for the samples. TGA of prepared polymers was recorded using thermal analyzer Perkin Elmer 4000 with heating rate 10.0 deg. /min in the range 50-800 °C. TGA records were carried out at polymer research group laboratory, faculty of science, Tanta University. This technique allowed us to determine the temperature at which thermal degradation commenced (T_{on_set}) and the change in mass as a function of temperature increase. Derived thermogravimetric curves (DrTG) were used to identify the maximum degradation temperature (T_{deg_max}) (Abd-Alla and Aly, 1990).

Methods

Synthesis of poly L-Lactic acid

Direct polycondensation polymerization was used to create PLLA, and the general process was as follows: L-(+) lactic acid (0.1 mol) was introduced to 30 mL of the mixture of xylene and Decalin in a round flask equipped with a Dean and Starck apparatus, along with a catalyst and coupling agent (**Table 1**). For 25 hours at 250°C, the reaction mixture was stirred while in reflux. The generated PLLA was filtered. A semi-solid product which produced dissolved in chloroform, and then filtered again to eliminate catalyst that had not yet

dissolved. Diethyl ether was added to the polymer solution in chloroform to precipitate it. After the solvents were evaporated under vacuum using a

Rotary evaporator. The product was washed with absolute ethanol and dried in vacuum oven at 30°C.

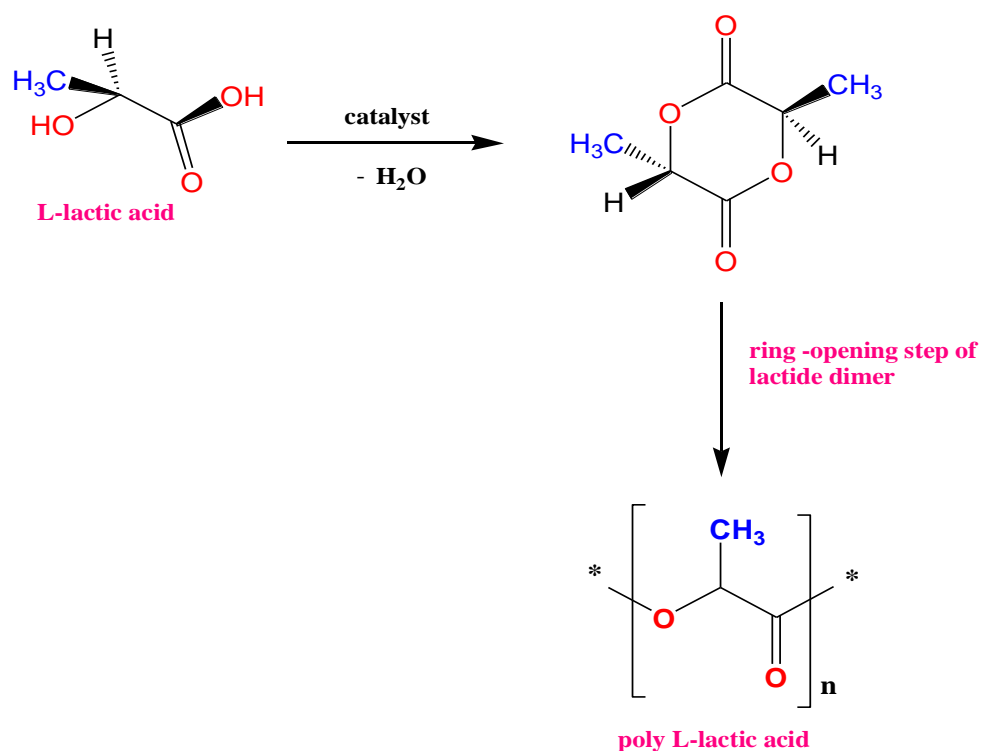
Table (1): conditions of PLLA synthesis

Code of polymer	Type of catalyst	Type of coupling agent	Ratio catalyst/ coupling agent (total weight 75 mg)
A1	ZnO	ZnCl ₂	3:5
A2	ZnO	ZnCl ₂	1:1
A3	CaCl ₂	ZnCl ₂	1:2
A4	Al ₂ O ₃	Maleic anhydride	2:2
A5	MgO	MgCl ₂	1:1

Results and discussion

The PLLA synthesis was completed as described in the experimental part. According to **scheme (1)**, PLLA's polycondensation polymerization was

carried out. The manufactured PLLA samples were evaluated using FT-IR, viscosity to determine molecular weight, and acid value.



Scheme 1. Synthesis of PLLA.

FT-IR Spectroscopy

The PLA's FT-IR spectra showed distinctive ester absorption peaks (1761 and 1092 cm^{-1} for $-\text{COO}-$ and $-\text{O}-$, respectively), as well as $-\text{CH}_2-$ and CH_3 groups ($2948\text{--}2998\text{ cm}^{-1}$). The large $-\text{OH}$ stretch peak at 3405 cm^{-1} found for PLA is diminished as lactic acid polymerizes because the hydroxyl group combines with the carboxylic group of another molecule. In the case of PLA, the hydroxyl absorption peak

almost vanished, suggesting that there were less hydroxyl groups, and as the polymer was further produced, a stronger absorption peak of $\text{C}=\text{O}$ stretching (1761 cm^{-1}) was seen (Cardoso *et al.*, 2013). The amorphous PLA phase is represented by the absorption band at 870.8 cm^{-1} , while the crystalline PLA phase is represented by the absorption band at 755.7 cm^{-1} (Diani and Gall, 2006).

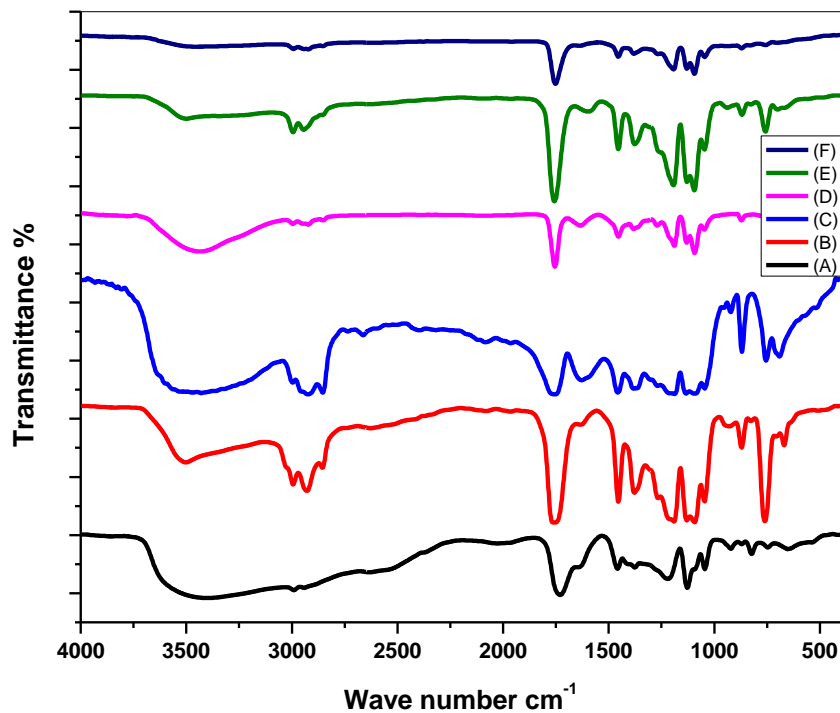


Fig. (1): FT-IR spectra of (A) L-Lactic acid monomer, (B) A1, (C) A2, (D) A3, (E) A4, and (F) A5.

Viscosity of PLLA

One popular approach for determining the molecular weight of a polymer is to measure its viscosity.

The molecular weight grew along with the viscosity. Based on the findings, greater molecular weight PLLA was synthesized utilizing ZnO as a catalyst

and ZnCl_2 as a coupling agent in a 3:5 ratio. This outcome demonstrated ZnO 's capacity to take water molecules out of the LA monomer and its

effectiveness in producing lactide dimers. A crucial factor in lengthening the polymer chain was ZnCl_2 .

Table 2: Viscosity of Polycondensation of lactic acid in the presence of different coupling agent and catalysts

Code of polymer	η_r	η_{sp}	$\eta_{intrinsic}$	M.wt
A1	1.0248	0.0248	0.1229	4297.9
A2	1.0137	0.0137	0.0682	2093
A3	1.0174	0.0174	0.0867	2805.9
A4	1.0149	0.0149	0.0741	2318.2
A5	1.0193	0.0193	0.0961	3180.6

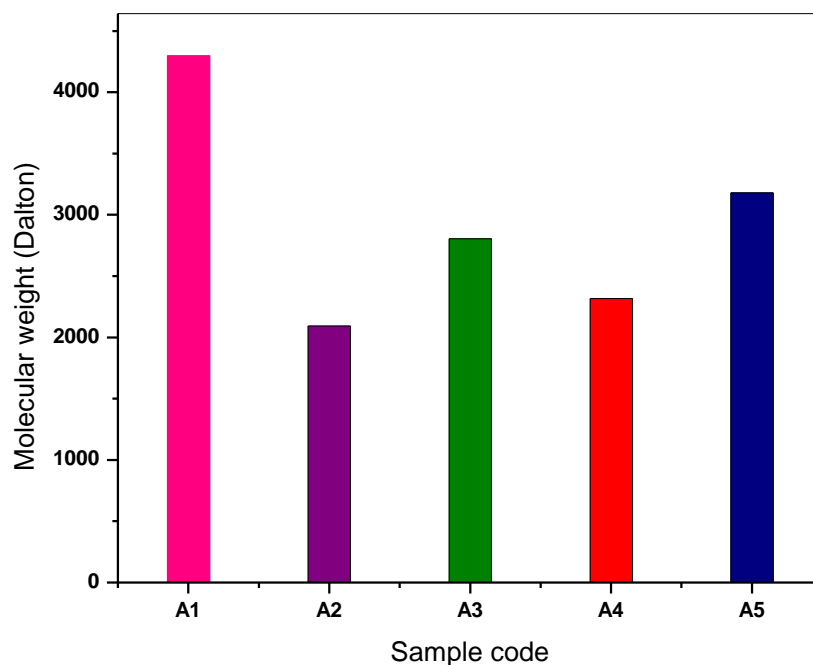


Fig. (2): Molecular weight of PLLA samples.

Acid value determination

Titration was used to determine the acid value as described in the experimental part. The free carboxylic

groups were connected to the acid value. The largest molecular weight is indicated by the lowest acid value.

Table 3: Acid value of PLLA

Code of polymer	Acid value (mg KOH/g)
A1	15.16
A2	31.2
A3	56.1
A4	80.14
A5	31.2

Thermal Gravimetric Analysis of PLLA

The thermal stability of the synthesized PLLA was examined by measuring the sample weight loss at a programmed rate of heating 10°C/min under stream of nitrogen gas depicted in Fig. 3. Shows a good thermal stability as there was no significant losing of the weight up to 175°C. Only

one major decomposition step in discernible from the thermogram occurred at 280°C with maximum rapid weight loss almost 100% within the range of 200-310°C. This stage may be due to the cleavage and total volatilization of the polymer chain. The degradation of PLLA at the temperature range 300-400°C is most probably associated with the loss of ester groups (**Reaction, 2018**).

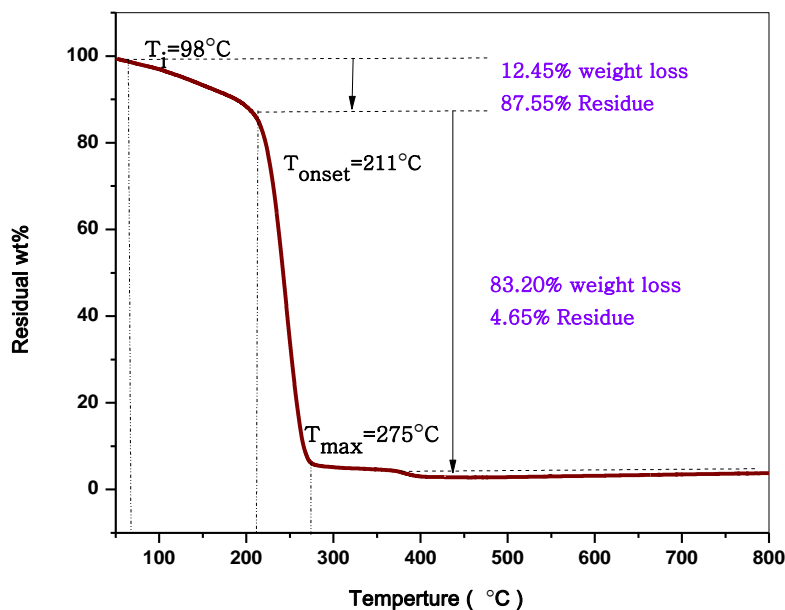


Fig. 3: TGA of PLLA.

Conclusion

Direct polycondensation polymerization using catalysts and coupling agents was used to create PLLA. To describe the structure of PLLA and its molecular weight, FT-IR, viscosity, TGA, and acid value analytical methods were used to

examine the substance. In order to create PLLA with a high molecular weight, the polymerization of PLLA with the help of the catalyst ZnO and the coupling agent ZnCl₂ is crucial.

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تصنيع وتوصيف البولي لاكتيك عن طريق التكتيف المتعدد المباشر

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تم بذل جهود علمية وهندسية كبيرة في اكتشاف البوليمرات وتطويرها وتطبيقها نتيجة للتقدم الاجتماعي والاقتصادي. أحد البوليمرات الحيوية الواعدة هو حمض اللاكتيك ، والذي يمكن تصنيعه من مواد خام متجددة غير سامة. نظراً لصفاتها بما في ذلك التوافق الحيوي ، والتحلل البيولوجي ، والقوة الميكانيكية ، والقدرة على المعالجة ، فقد أصبح بولي لاكتيك مادة بوليمرية حاسمة للتطبيقات الطبية الحيوية. من خلال تخمير السكريات من مصادر متجددة مثل الذرة وقصب السكر ، يمكن إنتاج حمض اللاكتيك. وبالتالي ، فإن بولي لاكتيك عبارة عن بوليمر غير سام وصديق للبيئة له خصائص تسمح باستخدامه في جسم الإنسان. نظراً لتوافقه وقابليته للتحلل البيولوجي ، فقد اجتذب حمض بولي لاكتيك اهتماماً كبيراً من المجتمع العلمي. بالنسبة لبولي لاكتيك ، هناك العديد من الاستخدامات. تم استخدام التكتيف المتعدد المباشر لإنشاء البولي لاكتيك ، جنباً إلى جنب مع مجموعة متنوعة من المحفزات وعوامل الاقتران. باستخدام التحليل الطيفي ، تم تحديد اللزوجة لتحديد الوزن الجزيئي ، وقيمة الحمض ، والتحليل الجاذبية الحرارية.