Available online www.jocpr.com

Journal of Chemical and Pharmaceutical Research, 2012, 4(1):175-179

Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

Design, synthesis and characterization of elastomers based on itaconic acid

J. Margaret Marie* [1,2], R. Puvanakrishnan[2], and R. Nanthini[3]

[1]*Department of Chemistry, Women's Christian College, Chennai, India*
[2]*Department of Biotechnology, Central Leather Research Institute, Chennai, India*
[3]*PG and Research Department of Chemistry, Pachaiyappa's College, Chennai, India*

ABSTRACT

Aliphatic polyester elastomers have emerged as a promising family of biomaterials for drug delivery and tissue engineering. The potential biomaterials should be elastic and flexible, so as to mimic the mechanical properties of natural tissue. Herein, we report the design and synthesis of elastomers containing multifunctional non-toxic monomers; citric acid (CA), 1,4-cyclohexanedimethanol (CHDM) 1,12-dodecanediol and itaconic acid (IA). CA as a reactive monomer can undergo polycondensation in the absence of toxic catalyst. Also, its multifunctionality can favour the formation of crosslinks during thermal curing conditions. The polyesters were characterized using FT-IR and NMR spectroscopy. The thermal properties were studied using DSC and TGA techniques. The Young's modulus, UTS, % elongation and swelling experiments revealed that the mechanical and swelling characteristics of the polyesters could be controlled by modifying the monomers. The solubility tests revealed that the pre-polymers were soluble in common organic solvents therefore facilitating processing ability for different applications. The insolubility of post-polymerised polyesters confirmed that they were elastomers this result was evidenced by the T_g which were well below the body temperature. As all the monomers used in these materials have previously been utilized in other biomaterials the synthesized elastomers could be excellent candidates as future biomaterials.

Keywords: Citric acid; 1,12-dodecanediol; 1,4-cyclohexanedimethanol; bioelastomer; polyester.

INTRODUCTION

Synthetic polyester elastomers, especially unsaturated polyesters, have emerged as an important class of biomaterials that find wide spread applications in drug delivery, tissue engineering, gene therapy, aerospace, microelectronics and packaging [1, 2, 3]. Most of the biodegradable elastomers that have been developed require complex and costly synthesis procedures, which translate into higher manufacturing costs which hinder the commercial and clinical implementation of their use [4]. Further, selection of monomers for biomaterial syntheses is crucial for determining and controlling the functionality and biocompatibility of the biomaterials to be produced. It is essential to obtain new monomers having unique structures and by using eco-friendly methods, which would meet the required property after polymerization [5]. Recently, there is an increased attention in using citric acid and itaconic acid as a robust multifunctional monomer for biomaterial syntheses [6]. In earlier works, several investigators have reported scaffolds fabricated from elastic polyesters based on multifunctional monomers, in particular polyoctanediol citrate (POC) or polyglycerol sebacate (PGS) [4]. The high demand for new materials requires the preparation of new polymers with enhanced mechanical and thermal properties and the copolymerization technique has been widely used to achieve this target [7].

To our knowledge no study has systematically investigated polyester elastomers combining citric acid and itaconic acid in combination with aliphatic diols as comonomer by catalyst free reactions. In this paper we report the synthesis and characterization of two polyesters: Poly(1,12-dodecanediol citrate-*co*-1,12-dodecanediol itaconate)

(**P2**) and Poly(1,4-cyclohexanedimethanol citrate-*co*-1,4-cyclohexanedimethanol itaconate) (**P8**). All the monomers used have been previously used in other biocompatible polymers and so cytotoxicity was expected to be low.

MATERIALS AND METHODS

Synthesis of the polyesters:

The pre-polymers were synthesized by catalyst-free melt-condensation technique. Equimolar amounts of diol (DD or CHDM) and acids [Diol:(CA+ IA) = 1:1] were placed in a three-necked round-bottom flask and the monomer mixture was first heated up to 160-165 °C followed by heating at 140-145 °C for 3 h under a constant stream of nitrogen. The pre-polymers thus obtained were dissolved in 1, 4-dioxane [20% w/w solution] and the resulting pre-polymer solution was used for film preparation without further purification [8]. Films for mechanical and structural analysis were cast into Teflon petri dishes and placed in an air oven maintained at 80 °C for 24 h for post polymerization of the pre-polymers.

Polymer characterization:

Fourier transform infrared (FTIR) spectra were obtained at room temperature (27 °C) using ABB MB 3000 FT-IR SPECTROMETER. Pre-polymer samples were prepared by a solution casting technique (5 % pre-polymer solution in dichloromethane) over a KBr crystal. The ^{1}H NMR spectra for pre-polymers were recorded using a JOEL NMR spectrometer. The pre-polymers were purified by precipitation in water with continuous stirring followed by freeze-drying and they were then dissolved in $CDCl_3$ in 5 mm outside diameter tubes. Solubility of all the prepolymers was determined in various solvents qualitatively. Differential scanning calorimetric (DSC) thermograms were recorded in the range of -70 °C to 150 °C using DSC Q200 V23.10 Build 79 at a heating rate of 1 °C min^{-1} under nitrogen. The mechanical properties of the polyesters were measured with Tinius Olsen h10K-S UTM testing machine the load cell is of 5 N. The dog bone-shaped polymer film strips were prepared according to ASTM D 628 (30 mm × 5 mm × 5mm; length × width × thickness) and pulled at a strain rate of 1 mm/min. Values were converted to stress-strain and plotted. Young's modulus was calculated from the initial slope of the curve of the tensile stress versus strain.

Swelling Experiments:

The percentage swelling of the polyester was measured in DMSO as follows:

10 mm diameter discs of the polymer films were punched out from the film and soaked into 15 mL of DMSO at room temperature (27 °C). The discs were taken out of the solvent after 24 h and their weights were measured after wipe-cleaning their surfaces with a lint-free paper. The percentage swelling of the discs was calculated using the expression $[(M_w - M_o)/M_o] \times 100\%$, where M_o and M_w represent the disc masses in dry and wet conditions, respectively. After the swelling experiments, the discs were dried to constant weight and sol content was calculated using the expression $[(M_o - M_d)/M_d] \times 100\%$ where M_o and M_d represent the disc masses in pre and post swelling(dried) states.

RESULTS AND DISCUSSION

Polymer characterization

The synthesized polyester elastomers features ester cross-links and hydroxyl groups directly attached to the backbone [9]. The FTIR spectra of all the synthesized pre-polymers (Fig 1) show a strong absorption band at around 1733 cm^{-1}, which is characteristic absorptions of carbonyl stretching vibrations of ester groups and thus confirmed the formation of polyesters [10-12]. The bands centered at around 2921 and 2851cm^{-1} were assigned to methylene (-CH_2-) groups for the diacids/diols and observed in all the spectra of the polyesters [13]. The broad stretch at 3404 and 3506 cm^{-1} was attributed to the stretching vibrations of the hydrogen-bonded carboxyl and hydroxyl groups [14, 15]. The characteristic absorption at around 1635 cm^{-1} corresponded to the alkenyl stretching (C=C bond) due to the presence of itaconic acid in the polymeric chain [16-18].

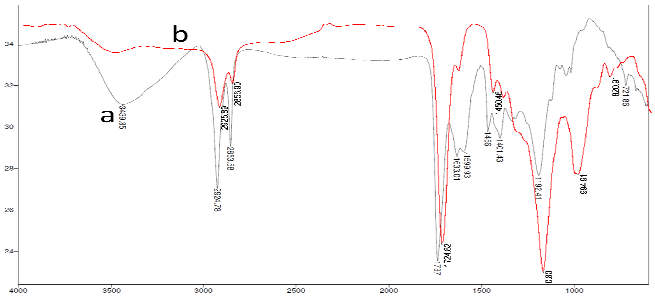

Fig 1: IR spectra of a) P2 and b) P8

The purified pre-polymers were characterized by ^{1}H NMR. A proposed structural formula for the resulting copolyesters (Fig 2) showed the correlation between the different structural components and the observed chemical shifts of the pre-polymers. The multiple peaks around 2.8 ppm, and 4.1 ppm [4, 8, 11] were attributed to the protons in –C<u>H</u>$_2$–group and alcoholic –O<u>H</u> group from citric acid. The peak at around 3.6 ppm could be due to the proton signal of –OC<u>H</u>$_2$CH$_2$- from diol [4]. The peaks at 0.9, 1.3 and 1.6 ppm were attributed to –C<u>H</u>$_2$- protons of 1, 12-dodecanediol and 1,4-cyclohexanedimethanol with the peaks overlapping in P2. The alkene peaks at around 5.8 and 6.2 ppm evidence the fact that the double bonds of itaconic acid were not involved in crosslinking. The absence of these peaks would have meant the double bonds were altered.

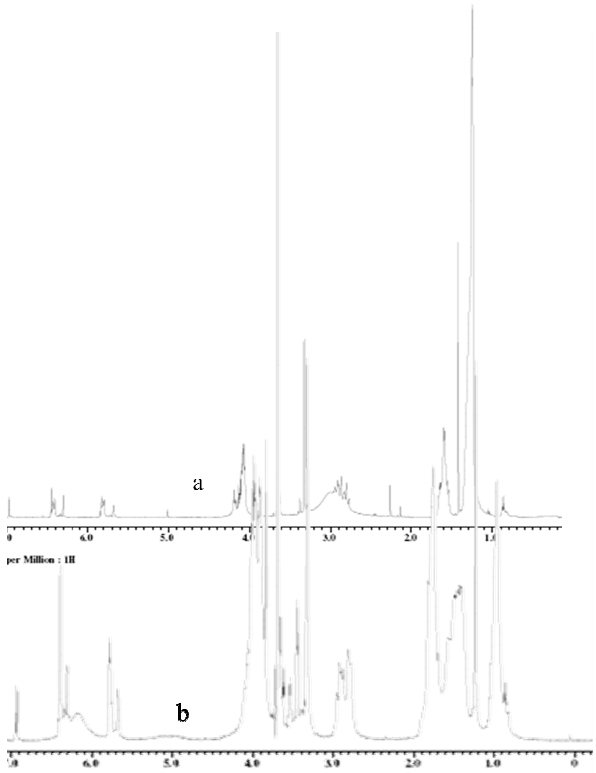

Fig 2: 1HNMR spectra of a) P2 and (b) P8

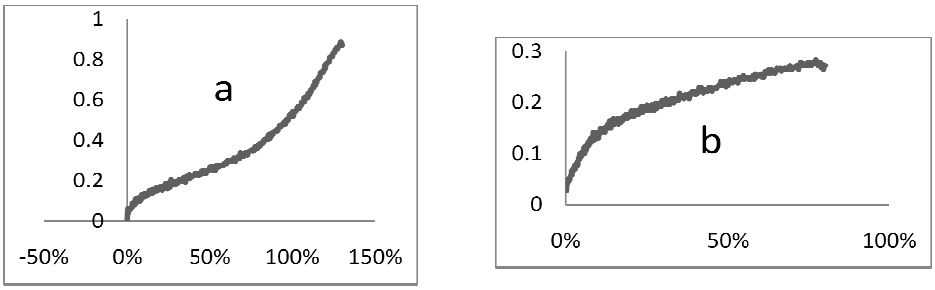

Fig 3: Stress-strain curves of a) P2 and b) P8

Tensile tests on the polymer films revealed the Young's modulus (E) of the polymers P2 and P8 were 1.05 and 0.88 MPa respectively. The ultimate tensile strength was 0.27 and 0.87 for P2 and P8. The % elongation at break was 80 % for P2 and 130 % for P8. Crosslink density was 141 and 119 for P2 and P8 respectively. Figure 3 depicts the typical stress-strain curves of the synthesized polyesters. It could be noted that the increase in crosslink density of P2 could be due to the closer packing of the layers due to DD when compared to CHMD. Thus it is evident that the mechanical properties of the elastomers can be controlled by substituting different diol units. This difference in properties could be useful for a variety of biomedical applications. The Young's modulus were closer to that of human thoracic aorta (0.60 MPa), elastin(1.1 MP) and myocardium of human (0.02-0.5 MPa) [19,20].

Thermal Analysis

The thermal studies revealed that the elastomers were thermally stable. The DSC analysis of both the polyesters showed T_g below room temperature, a characteristic feature that determined their elastomer-like behavior [8]. As shown in figure 4, the T_g of P2 (-0.63 °C) was lower than P8 (13.92 °C).

Swelling Experiments

Equilibrium swelling was studied in DMSO which was chosen because of its high boiling point. The swelling experiments revealed that P2 and P8 swelled to 52.41% and 169 % of their original size respectively. The sol content of the polyester elastomers P2 and P8 was calculated as 3.17 % and 13.12 % respectively. The relatively small amount of the sol content confirmed the successful formation of polymer network. Although DMSO dissolved the pre-polymer, the final post-polymerized samples did not dissolve in DMSO even after soaking for several days. The low sol content indicated the very little presence of small oligomers trapped with the polymeric network. As the polymer-polymer intermolecular forces were high due to cross-linking and strong hydrogen bonding, the samples did not completely dissolve. This result was shown to be in agreement with the FTIR analysis which showed the presence of hydrogen bonded -OH and -COOH groups [8]. The high swelling of the P8 in DMSO could be due to the weakening of the intermolecular interactions and disruption of physical cross links between the polymer chains. Also it could be due to lesser crosslink density than that of P2 polyester which had a more rigid network.

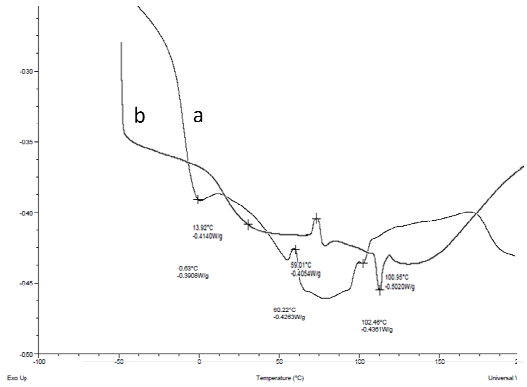

Fig 4: DSC curve of a) P2 and (b) P8

CONCLUSION

The polyester elastomers, poly (1,12-dodecanediol citrate-co-1,12-dodecanediol itaconic acid) (P2); poly (1,4-cyclohexanedimethanol citrate-co-1,4-cyclohexanedimethanol itaconic acid) (P8) were synthesized using melt condensation polymerization and thermal curing condition. The mechanical and thermal properties of the polyesters showed that P2 had better cross-linking than that of P8. Also, T_g evidenced their elastomeric nature. The polymers had appreciable swelling characteristics which substantiate their cross-linking abilities. Thus it is noticed that the choice of monomers can largely influence the physical properties of the elastomers so as to suit them for the requirements of various biomedical applications.

REFERENCES

[1] R Narasimharao; S Shyale; K Prakash. *J. Chem. Pharm. Res.*, **2011**, 3(1), 360.
[2] DG Barrett; MN Yousaf. *Molecules*, **2009**, 14, 4022.
[3] PN Dave; NN Patel. *J. Chem. Pharm. Res*., **2011**, 3(1), 6.
[4] J Yang; AR Webb; SJ Pickerill; G Hageman; GA Ameer. *Biomaterials*, **2006**, 27, 1889.
[5] KS Bhat. *J. Chem. Pharm. Res.*, **2011**, 3(3), 286.
[6] RT Trans; Y Zhang; D Gyawali; J Yang. *Recent Pat. Biomed. Eng*., **2009**, 2, 216.
[7] BL Hiran; R Boriwal; SN Paliwal; D Singh. *J. Chem. Pharm. Res.*, **2011**, 3(1), 793.
[8] I Djordjevic; NR Choudhury; NK Dutta; S Kumar. *Polymer*, **2009**, 50, 1682.
[9] Y Wang; BJ Sheppard; R Langer. *Mat. Res. Soc. Symp. Proc.*, **2002**, 742, N11.1.1.
[10] DK Song; YK Sung. *J. Appl.Polym. Sci.*, **2003**, 56, 1381.
[11] S Pasupuleti; A Avadanam; G Madras. *Pol. Eng and Sci.*, **2011**, 51(10), 2035.
[12] L Lei; T Ding; R Shi; Q Liu; L Zhang; D Chen; W Tian. *Polym. Degrad. Stab.*, **2007**, 92, 389.
[13] MM Brioudea; DH Guimaraesa; RDD Fiuzaa; LAS Pradob; JS Nadia; M Josea. *Mater. Res.*, **2007**, 10, 335.
[14] D Xie; D Chen; B Jiang; C Yang. *Polymer*, **2000**, 41, 3599.

[15] LY Lee; SC Wu; SS Fu; SY Zeng; WS Leong; LP Tan. *Eur. Polym. J.*, **2009**, 45, 3249.
[16] MA Shaker; JE Dore; HM Younes. *J. Biomater. Sci.- Polym E.***2010**, 21, 507.
[17] D Gyawali; P Nair; Y Zhang; RT Trans; C Zhang; M Samchukov; M Makarov; HKW Kim; J Yang. *Biomaterials*, **2010**, 31(34), 9092.
[18] S Kaihara; S Masumura; JP Fisher. *Eur. J. Phrm. Biopharm*. **2008**, 68, 67.
[19] J Gosline; M Lillie; E Carrington; P Guerette; C Ortlepp; K Savage. *Phil. Trans. R. Soc. Lond. B.* **2002**, 357, 121.
[20] QZ Chen; A Bismarck; U Hansen; S Junaid; MQ Tran; SE Harding; NN Ali; AR Boccaccini. *Biomaterials*, **2008**, 29, 47.