

## Poly(L-lactide)-Poly(ethylene glycol) Multiblock Copolymers: Synthesis and Properties

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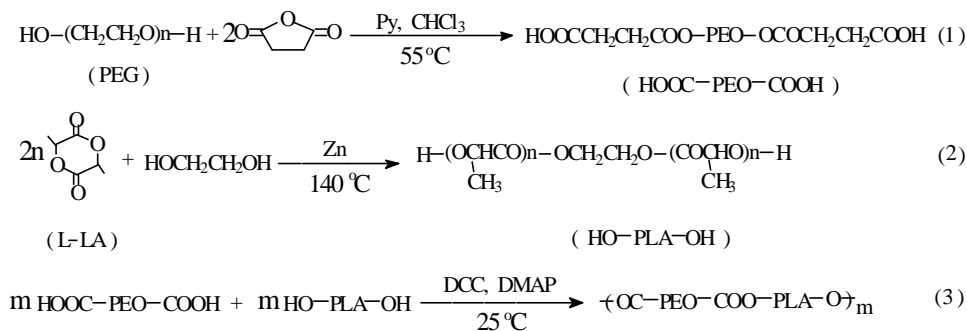
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**Abstract:** Poly (L-lactide)-poly(ethylene glycol) multiblock copolymers with predetermined block lengths were synthesized by polycondensation of PLA diols and PEG diacids. These copolymers presented special properties, such as better miscibility between the two components, low crystallinity and better hydrophilicity, which can be modulated by adjusting the block lengths of the two components.

**Keywords:** Poly (L-lactide), poly(ethylene glycol), biodegradability, multiblock copolymer, miscibility, crystallinity, hydrophilicity.

Recently, growing interest was given to a new class of biomaterials: the polyether-polyester block copolymer. Poly (ethylene glycol) (PEG) and poly (L-lactide) (PLA) are the most widely used polyether and biodegradable polyester components, owing to their outstanding properties. Copolymerization offers the possibility to combine the hydrophilicity of PEG and biodegradability of PLA and lower the crystallinity of the copolymers to make a wide range of polymeric materials for medical applications. Various PLA-PEG block copolymers synthesized by different ways have been reported, and they showed versatility in both mechanical as well as biodegradation properties<sup>1-4</sup>. However almost all of these copolymers are triblock. It appears interesting to consider the multiblock ones. Lee *et al.* have prepared such PLLA - PEG multiblock copolymers, and investigated the crystallization behavior of the copolymers<sup>5</sup>. However a much wider investigation should be done on the molecular structure, characterization the property of the PLLA - PEG multiblock copolymers. Compared to the triblock one with equal Mn, multiblock copolymer has more and shorter PEG and PLA segments, which alternate in the polymer chain. Consequently, it is possible to get some special properties such as better miscibility between the two components and lower crystallinity. Thus the degradability of the copolymer is expected to be enhanced.

The synthetic procedure of the PLA - PEG multiblock copolymer can be outlined as **Scheme 1**<sup>6-8</sup>. Along this way, a series of multiblock copolymers with different PEG and PLA segments were synthesized. The multiblock copolymers are presented as PLAx-PEGy, where x and y are the molar mass of the PLA and PEG macromonomers respectively. **Table 1** gives out some direct information about all the related polymers.

**Scheme 1** Outline of synthetic procedure

In all cases, the copolymers exhibited unimodal molar mass distribution in GPC graphs. In other words, the copolymers did not contain unreacted PEG diacids or PLA diols. The molar masses and  $[\eta]$  of copolymers are much higher than those of the starting macromonomers.

**Table 1** Molar mass and  $[\eta]$  data of PLA-PEG multiblock copolymers

Copolymer	$\overline{M}_w^a/10^3$	$\overline{M}_n^a/10^3$	$\overline{M}_w/\overline{M}_n^a$	PLLA/PEG <sup>b</sup>	$[\eta]$
PLA 1000 – PEG 600	14.3	11.0	1.3	1.04	0.28
PLA 2000 – PEG 600	27.4	18.1	1.5	0.95	0.48
PLA 3000 – PEG 600	30.7	20.3	1.5	1.00	0.50
PLA 1000 – PEG 2000	13.2	8.6	1.5	0.86	0.33
PLA 2000 – PEG 2000	16.7	11.3	1.7	0.95	0.45
PLA 3000 – PEG 2000	14.9	10.3	1.5	1.08	0.38

<sup>a</sup> Determined by GPC measurement.

<sup>b</sup> Molar ratio of the two component segments in the copolymers, calculated from <sup>1</sup>H NMR spectra.

<sup>1</sup>H NMR spectrum of the multiblock copolymers was done. It could be seen that the spectrum bands of methylene protons end units of succinic anhydride half ester moved appreciable distance down to low field after copolymerization. And the band corresponding to –CH– in PLA end groups moved from 4.33 ppm to 5.13 ppm. These motions constitute evidences that copolymerization happened between the two macromonomers and there were few end function groups remain unreacted. The thermal properties of the copolymers and their macromonomers were investigated by DSC. Each of copolymers showed only one meditated T<sub>g</sub> rather than two separated. That means the two components got some miscibility in the multiblock copolymer, at least in the amorphous domain, rather than incompatible in the mixture of their homopolymers<sup>9</sup> as well as in PEG-PLA-PEG triblock copolymers<sup>3</sup>.

In all cases, PEG and PLA segments showed decreased crystallinity after copolymerization due to the hindrance between each other. The longer the segment length of one component is, the higher its crystallinity and the lower the crystallinity for the other component, as shown in **Table 2**. The X-ray diffraction analysis result of the macromonomers and multiblock copolymers agree well with that from DSC

measurement.

**Table 2** Crystallinity of PEG and PLA segments in the multiblock copolymers<sup>#</sup>

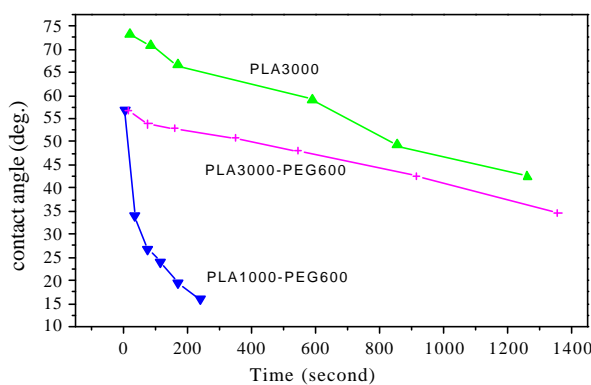
Segment	Crystallinity: PEG segment\PLA segment		
	PLA 1000	PLA 2000	PLA 3000
PEG 600	- \ -	- \ +	- \ +
PEG 2000	+ \ -	+ \ +	- \ +

<sup>#</sup> + means crystalline, - means amorphous

**Figure 1** shows the contact angle vs. time curves of the copolymers and PLA macromonomer. PLA macromonomers had almost the same initial contact angle (72~73°). The initial contact angles of the copolymers was in the range of 44 to 67°, which were lower than those of PLA macromonomer. The contact angle to time curves of PLA 2000 – PEG 600 and PLA 3000 – PEG 6000 showed similar trends as PLA, *i.e.* almost linear decrease with time. In contrast, the other copolymer, namely PLA 1000 – PEG 600, PLA 1000 – PEG 2000, PLA 2000 – PEG 2000 and PLA 3000 – PEG 2000, presented a very rapid decrease of contact angle. That means that the hydrophilicity of these copolymers was greatly improved. Even PLA 2000 – PEG 600 and PLA 3000 – PEG 600 showed higher hydrophilicity than corresponding PLA macromonomer.

In conclusion, multiblock PLA - PEG copolymer was successfully synthesized by polycondensation of PLA diol and PEG diacid. This copolymer showed an improved miscibility between the two components. The crystallinity of the copolymers was greatly decreased in comparison with PLA and PEG homopolymers, and it could be modulated by adjusting the block lengths of both components. Contact angle measurement confirmed the strong improvement in hydrophilicity as referred to PLA homopolymer. These properties should be interesting for biomedical uses, in particular as drug carrier for controlled releasing as well as cell scaffold material in tissue engineering.

**Figure 1** Contact angle vs. time curves of PLA3000 and two compolymers



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