

Synthesis of Novel Dendritic α -Glycol Ligands Derived from DL-Dithiothreitol and Their Application to Ring-opening Polymerization of ϵ -Caprolactone

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(Received June 24, 2005; CL-050810)

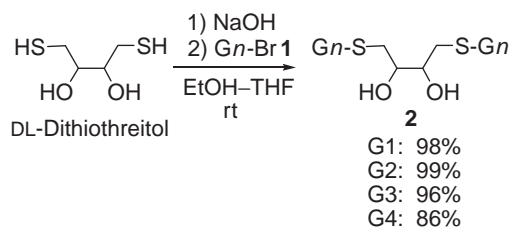
A series of dendritic ligands with an α -glycol core was synthesized through the coupling of DL-dithiothreitol with poly(aryl-ether) dendron in high yields. The corresponding aluminum dendrimers were applied as initiator to ring-opening polymerization of ϵ -caprolactone. A dendritic effect on the polydispersity (M_w/M_n) of poly(ϵ -caprolactone) was observed.

Dendrimers are fascinating molecules due to their unique physical and chemical properties.¹ In point of the view of their character, encapsulation of functional or catalytic sites into the interior of dendrimers is one of the important goals. Thus, recently several incorporations of metals into dendrimers at the core have been attempted.²

Although dendritic ligands with a ω -glycol core (TADDOL) have been reported, these dendrimers have been prepared *via* a multistep reaction.³ Herein, we wish to report the very simple preparation of dendritic α -glycol ligands by use of DL-dithiothreitol as the core unit, and the ring-opening polymerization of ϵ -caprolactone using the corresponding aluminum dendrimer as initiator. Poly(ϵ -caprolactone) is one of the most attractive aliphatic polyesters because of its widely recognized biodegradability.⁴ In order to enhance the strength of poly(ϵ -caprolactone) and to control the biodegradability of it, a more reactive and more effective polymerization initiator with a high level of molecular design has been desired.⁵

Dendrimers having an α -glycol core **2** were synthesized according to Scheme 1. To a solution of sodium hydroxide in etha-

nol was added first DL-dithiothreitol in ethanol to provide the corresponding sodium thiolate, and then was added poly(aryl-ether) dendritic benzyl bromide **1^h** (structural formulas of *G_n* are shown in Figure 1), which was dissolved in tetrahydrofuran under an argon atmosphere. After stirring for 5 h at room temperature, the reaction mixture was concentrated in vacuo and then was purified by column chromatography on silica gel. Dendrimers **2** were obtained in high yields in all cases.⁶



Scheme 1. Preparation of dendrimers **2**.

The utility of dendrimers **2** as dendritic ligand was demonstrated by the ring-opening polymerization of ϵ -caprolactone using the corresponding aluminum dendrimer **3** as initiator.

As shown in Scheme 2, by the addition of an equimolar amount of diethylaluminum ethoxide Et_2AlOEt to a toluene solution of **2**, the corresponding aluminum alkoxide dendrimer **3** was prepared in situ with the evolution of ethane as a gas.^{7,8} In the case of using **3** as polymerization initiator (Figure 2), it is expected that **3** not only acts as *initiator*, but also can control the polymer propagation step through the coordination of its aluminum core.⁹

Ring-opening polymerization of ϵ -caprolactone was performed by the addition of the above-prepared toluene solution

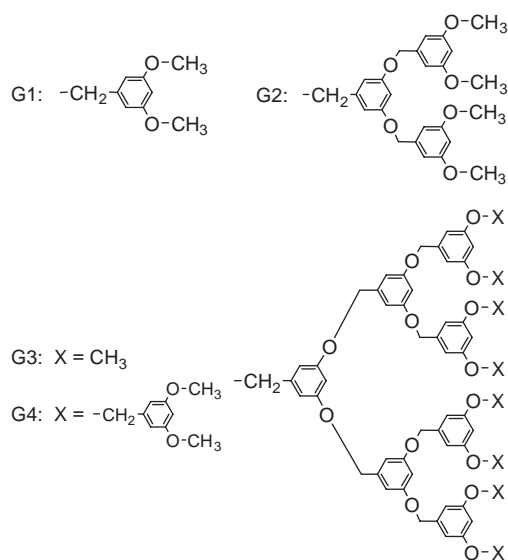
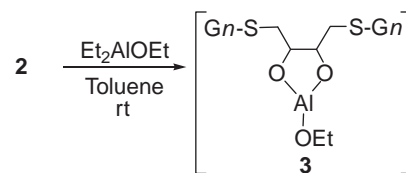


Figure 1. Structural formulas of *G_n* dendrons ($n = 1-4$).



Scheme 2. Preparation of aluminum dendrimers **3**.

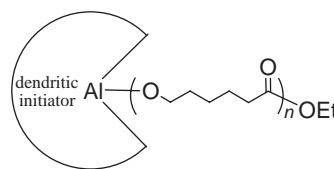
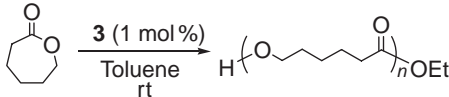


Figure 2. Plausible intermediate of propagation step using **3** as initiator.

Table 1. Ring-opening polymerization of ϵ -caprolactone using **3** as initiator


| Entry | Gn of 3 | Conversion ^a /% | M_n^b | M_w/M_n^b | Yield ^c /% |
|-------|----------------|-------------------------------|---------|-------------|--------------------------|
| 1 | G1 | 93 | 19,000 | 1.19 | 86 |
| 2 | G2 | 92 | 22,000 | 1.16 | 85 |
| 3 | G3 | 94 | 21,000 | 1.16 | 83 |
| 4 | G4 | 99 | 22,000 | 1.12 | 96 |

^aDetermined by ¹H NMR. ^bDetermined by GPC against polystyrene standard.

^c $\frac{(\text{Total weight of obtained polymer}) - (\text{Weight of } \mathbf{2})}{(\text{Weight of } \epsilon\text{-caprolactone})} \times 100$.

of **3** (1 mol %) to toluene solution of ϵ -caprolactone at room temperature under an argon atmosphere (Table 1).^{10,11} First, by employing the first-generation-derived dendritic initiator **3**[**G1**], the polymerization time was significantly shortened (1.5 h), compared to that using aluminum triisopropoxide as initiator (9.5 h).¹² While, even in the case of using a simple bidentate-coordinated initiator, which was prepared from *S,S'*-dimethyl-DL-dithiothreitol and Et₂AlOEt, polymerizations occurred rapidly (1.3 h).¹³ We assume that the dithiothreitol-derived ligand suppresses the aggregation of the aluminum alkoxide unit on the basis of the octahedral coordination of aluminum atom,¹⁴ thus dithiothreitol-derived initiators show the high reactivity.

We subsequently performed ring-opening polymerization using the higher-generation-derived dendritic initiators **3**. Also in these cases, polymerizations occurred rather rapidly, completing within 1.5–2.5 h. Interestingly, when a series of dithiothreitol-derived initiators **3** was employed, in all cases the number-average molecular weight (M_n) of poly(ϵ -caprolactone), which was determined by GPC, was nearly twice that expected. We are now investigating the reason of this enlargement of M_n .

Furthermore, the higher generation-derived initiators showed the narrower polydispersity (M_w/M_n) of poly(ϵ -caprolactone) (**3**[**G4**]: $M_w/M_n = 1.12$, Entry 4). This result is likely due to suppression of the transesterification of poly(ϵ -caprolactone) through coordination of the aluminum core; as a result, only ϵ -caprolactone, which is small in size, is activated, due to the quite bulky dendron, especially when a higher-generation-derived initiator is used. This relationship between the generation of the dendritic initiator **3** and M_w/M_n is one of the positive dendritic effects.¹⁵

We are currently trying to apply this dendritic ligand to other catalytic versions. The results will be reported in due course.

This work was supported by Industrial Technology Research Grant Program in '04 from New Energy and Industrial Technology Development Organization (NEDO) of Japan and by the research grant from Mitsui Chemicals, Inc.

References and Notes

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- 6 Selected data: **2**[**G3**] colorless glass; IR (CH₂Cl₂) 3492, 2938, 2838, 1597, 1430, 1205, 1155, 1052, 833 cm⁻¹; ¹H NMR (CDCl₃) δ (ppm) 6.64 (d, *J* = 2.1 Hz, 8H, ArH), 6.55–6.52 (m, 24H, ArH), 6.46 (t, *J* = 2.1 Hz, 2H, ArH), 6.39 (t, *J* = 2.1 Hz, 8H, ArH), 4.92 (s, 16H, OCH₂Ar), 4.90 (s, 8H, OCH₂Ar), 3.76 (s, 48H, OCH₃), 3.61–3.59 (m, 6H, SCH₂Ar, CH₂CH(OH)), 2.60–2.52 (m, 6H, SCH₂CH(OH)); ¹³C NMR (CDCl₃) δ (ppm) 160.9, 160.0, 139.2, 139.1, 108.0, 106.4, 105.2, 101.6, 101.0, 99.9, 70.6, 70.0, 69.9, 55.3, 36.6, 35.3; MALDI-TOF MS for C₁₁₈H₁₂₆O₃₀S₂Na *m/z*: Calcd: 2109.77 [(M + Na)⁺]; Found: 2110.56; Anal. Calcd for C₁₁₈H₁₂₆O₃₀S₂: C, 67.86; H, 6.08; S, 3.07%. Found: C, 67.82; H, 5.93; S, 2.90%.
- 7 Typical procedure: A toluene solution of diethylaluminum ethoxide (0.314 M, 0.30 mL) was added to a dry toluene solution (1.5 mL) of **2**[**G1**] (42.9 mg, 0.0944 mmol), and the solution was stirred at room temperature under an argon atmosphere for 2 h to prepare **3**[**G1**] in situ.
- 8 The formation of **3** was identified by ¹H NMR after removal of toluene in vacuo.
- 9 Previously reported dendritic initiators acted only as *initiator*, thus dendrons were located at the initiation terminus: I. D. Mecerreyes, P. Dubois, R. Jerome, J. L. Hedrick, and C. J. Hawker, *J. Polym. Sci., Part A: Polym. Chem.*, **37**, 1923 (1999); I. Gitsov, P. T. Ivanova, and J. M. J. Fréchet, *Macromol. Rapid Commun.*, **15**, 387 (1994).
- 10 Typical procedure: To a toluene solution (8 mL) of ϵ -caprolactone (1.136 g, 9.95 mmol), the prepared toluene solution (1.8 mL) of **3**[**G1**] was added at room temperature under an argon atmosphere. After stirring the resulting mixture for 1.5 h, the ring-opening polymerization was completed (monitored by TLC). After removal of toluene in vacuo, chloroform (5 mL) was added to the polymerization mixture. To methanol (500 mL) the chloroform solution was added dropwise, followed by the addition of 10% methanolic hydrochloric acid (10 mL). The resulting precipitate was filtered, washed with a large amount of methanol, and dried at room temperature for 15 h in vacuo (1.017 g).
- 11 **2** derived from initiator **3** could be easily separated from precipitated polymer mixture by GPC using JAIGEL-2H, 2.5H column.
- 12 Conversion: 97%, M_n : 12,000, M_w/M_n : 1.19, Yield: 93%.
- 13 Conversion: 96%, M_n : 18,000, M_w/M_n : 1.18, Yield: 94%.
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