Heterogeneous Polymerization of L-Leucine N-Carboxy Anhydride Initiated by Primary Diamines

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The heterogeneous polymerization of L-leucine N-carboxy anhydride in presence of acetonitrile using hexamethylenediamine (HM), ethylenediamine (ED) and bis(4-aminophenyl)ether (AP) as initiators has been investigated. The results indicate that the polymerization rates increase in the order: HM > ED > AP. The polymerization initiated by HM or ED shows that the degree of occlusion of the active chain ends is rather low compared to the system initiated by AP. IR, X-ray diffraction and electron microscopy of polymer samples reveal that the poly(L-leucine) fibres are precipitated in the form of z-helical conformation with extended chain crystals.

Recently, studies were carried out on the heterogeneous polymerization of various amino acid N-carboxy anhydrides in acetonitrile using butylamine as an initiator. It was found that the polypeptides forming the z-helix gave extended chain crystals, and polymers with zigzag conformation gave chain folded crystals.

In this note, three diamines, viz., hexamethylene-diamine (HM), ethylenediamine (ED) and bis(4-aminophenyl) ether (AP) have been used as initiators in the polymerization of L-leucine N-carboxy anhydride (NCA).

The L-leucine NCA was prepared as described in literature and purified by recrystallization from ethyl acetate-hexane, diethyl ether-hexane and isopropyl ether-hexane.

Polymerization—L-Leucine NCA (1.363 g, 0.434 mol/dm³) was dissolved in acetonitrile (20 ml) in a flask (100 ml capacity) with a silica gel column, into which the initiator (0.25 mol/² with respect to the monomer) dissolved in acetonitrile was added. The initiators used were hexamethylenediamine (HM), ethylenediamine (ED) and bis(4-aminophenyl) ether (AP). The mixture was homogenized and kept in a thermostat at 30°C without stirring to obtain the polymer as a precipitate. After a given time, the polymer was collected, washed with acetonitrile to remove the unreacted monomer and dried in vacuo at room temperature before it was weighed.

The percentage conversion of the monomer was determined gravimetrically using the expression:

\[
\text{Conversion (\%)} = \left(\frac{\text{wt of polymer} \times 100}{\text{113} \times \text{wt of L-leucine residue}}\right) / \left(\frac{\text{wt of NCA} \times 157}{\text{wt of L-leucine NCA}}\right)
\]

(1)

Microscopic observations of the polymerized crystals were carried out by an electron microscope (JEM-7 of Japan Electron Optics Lab.). The intrinsic viscosities of the obtained polymers were measured in trifluoroacetic acid (TFA) at 25°C using an Ubbelohde-type viscometer. The value of the Huggins' constant (\(k\)) was calculated using the Huggins equation:

\[
\eta_p/c = [\eta] + k[\eta]^2c
\]

The IR spectra of the polymers were recorded with KBr on a JAS spectrometer (Japan Spectroscopic Co.). X-ray diffraction patterns were obtained by the powder method using an RU-3V apparatus (Rigaku Denki Co) with CuK\(_\alpha\) beam.

The cloud point, polymerization time, conversion, intrinsic viscosities and the Huggins' constant are listed in Table 1. The polymerizing system became cloudy as when hexamethylenediamine (HM) and ethylenediamine (ED) were added to the monomer solution. On the other hand for bis(4-aminophenyl) ether (AP)-initiated polymerization the cloud point

<table>
<thead>
<tr>
<th>Initiator (abbreviation)</th>
<th>Cloud point (sec)</th>
<th>Polymerization time (hr)</th>
<th>Conversion (%)</th>
<th>[\eta]* (dl/gm -1)</th>
<th>(k)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hexamethylene-diamine (HM)</td>
<td>instantaneous</td>
<td>0.5</td>
<td>12.87</td>
<td>0.428</td>
<td>0.42</td>
</tr>
<tr>
<td>Ethylenediamine (ED)</td>
<td>instantaneous</td>
<td>0.5</td>
<td>25.13</td>
<td>0.546</td>
<td>0.25</td>
</tr>
<tr>
<td>Bis(4-aminophenyl) ether (AP)</td>
<td></td>
<td>144</td>
<td>93.08</td>
<td>1.240</td>
<td>0.25</td>
</tr>
</tbody>
</table>

* Intrinsic viscosity at 25°C in trifluoroacetic acid
Fig. 1—Conversion as a function of the polymerization time for the polymerization of L-leucine NCA in acetonitrile at 30°C initiated by: (a) hexamethylenediamine, (b) ethylenediamine and (c) bis(4-aminophenyl) ether; monomer concentration = 0.434 mol/dm³; mole ratio of monomer to initiator = 400.

appeared after 30 sec, suggesting that during the very early stages of polymerization, soluble oligo-L-leucines were formed, which on attaining a certain degree of polymerization, started precipitating at the cloud point. The results also showed that the polymerization rate was dependent on the kind of the initiator used and the rates followed the order: HM > ED > AP (Fig. 1). This might be due to high basicity of aliphatic diamines as compared to the aromatic one. Also the basicity of an aliphatic diamine increases with increasing its carbon chain.

The high conversion observed at a relatively short time for HM-initiated polymerization in comparison to butylamine-initiated polymerization previously reported, indicated that the two amino groups of HM can initiate the polymerization process simultaneously as a result of its flexible chain. However, a low conversion obtained when AP was used as an initiator (59% after 6 days) suggested that the two amino groups of such initiator could not initiate polymerization simultaneously as in the case of HM. This means that the poly(L-leucines) formed, in the system initiated by AP, contain different molecular chain lengths in comparison with ED or HM-initiated polymerization.

The IR absorption spectra of the resultant poly(L-leucine) initiated by HM, ED or AP exhibited amide-I band at 1650, the amide-II band at 1540 and three amide-V bands at 694, 657 and 614 cm⁻¹, respectively, suggesting that the polymer samples could be assign as the z-form. The formation of the z-helix suggested the formation of extended chain crystals of poly(L-leucine) during polymerization of the NCA.

The X-ray diffraction patterns of polymer samples obtained using the initiator HM, ED or AP showed a strong reflection at 2θ = 7.7° which is characteristic for the z-helical structure of poly(L-leucine). This is in good agreement with the IR analysis.

The crystals of poly(L-leucine) formed at the later stages of polymerization showed under electron microscope a mixture of fibre and lamellae. In the case of AP-initiated polymerization, the crystals formed during polymerization of the NCA at the initial stages, were in the form of thin fibres. Thereafter, the fibrous crystals just like super-helices were formed in the later stages of polymerization.

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References
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