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Some novel *N*-(carboxyacyl)chitosan filaments

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Abstract

A suspension of chitosan filaments in methanol was treated with each of maleic (**1**), (2-octen-1-yl)succinic (**2**), citraconic (**3**), phthalic (**5**), glutaric (**4**), and succinic (**9**) anhydrides to give rise to novel six *N*-(carboxyacyl)chitosan filaments (**F1**–**F5** and **F9**) at d.s. 0.09–0.75 for *N*-carboxyacyl. However, no *N*-(carboxyacyl)chitosan filaments were obtained by treatment with each of trimellitic (**6**), 4-methylphthalic (**7**) and pyromellitic (**8**) anhydrides due to a steric hindrance in the chitosan filaments. On the other hand, chitosan was *N*-carboxyacylated in a solution of 2% aqueous acetic acid–methanol (1:1, v/v) with each of **1**–**9** to give rise to *N*-(carboxyacyl)chitosan derivatives **C1**–**C9** (d.s. 0.39–0.80 for *N*-acyl) in 69–96% yields. Each of **C1**, **C4**–**C7**, **C9** and **F1** was soluble in water and in 1% aqueous sodium hydroxide solutions.

Keywords: N-Carboxyacylation; *N*-(Carboxyacyl)chitosan derivatives; Chitosan filaments; Intramolecular dicarboxylic anhydrides; *N*-(Carboxyacyl)chitosan filaments

1. Introduction

Natural and synthetic derivatives of chitin and chitosan containing carboxyl group in the molecule have been reported: muramic acid (Strominger & Ghuysen, 1967), 2-amino-2-deoxy-beta-D-glucopyranuronans (Horton & Just, 1973; Kato, Matsuo, & Kaminaga, 2002; Muzzarelli, 2000; Muzzarelli, Muzzarelli, Cosani, & Terbojevichi, 1999), *O*-(carboxyalkyl)chitins (Hirano et al., 1996; Izawa, Arakawa, & Kondo, 1986; Nishimura, Ikeuchi, & Tokura, 1984; Okimasu, 1958; Tokura, Nishi, Tsutsumi, & Somorin, 1983a; Tokura, Nishimura, & Nishi, 1983b; Trujillo, 1968), *N*,*O*-(carboxyalkyl and aryl)chitosans (Muzzarelli & Tanfani, 1982; Shigemasa et al., 1995), and *N*,*N*-dicarboxyethylchitosan (Hirano et al., 1996). Some *N*-(carboxyacyl)chitosans were also prepared by reactions with intramolecular carboxylic anhydrides including maleic (**1**), glutaric (**4**) and phthalic (**5**) (Hirano & Moriyasu, 1981), and succinic (**9**) (Yamaguchi, Arai, Itoh, & Hirano, 1981; Yamaguchi, Arai, Kaneko, & Itoh, 1982) anhydrides. As related compounds, some cyclic phthalimido derivatives of chitosan were reported (Kurita, Ichikawa, Fujisaki, & Iwakura, 1982). However, little is known about *N*-(carboxyacyl)chitosan filaments because of the difficulty in their direct spinning. The carboxyacylchitosan filaments are usable as new functional materials in many fields because of their hydrophilic and acidic properties (Hirano, 2002).

In the present report, six novel *N*-(carboxyacyl)chitosan filaments were prepared from chitosan filaments by the treatment with intramolecular carboxylic anhydrides (Scheme 1), and a steric hindrance on the chemical N-carboxyacylation in a filament state is examined from viewpoints of the structure of carboxylic anhydrides and the chitosan filament organization.

2. Experimental

2.1. Methods

The filament titer was expressed as denier for the weight (g) of a filament of 9000 m in length, the filament tenacity as gf/denier and the filament elongation as percentage in a dry condition. FTIR spectra (KBr disk) were recorded on a Jasco FTIR 5300 spectrometer (Jasco Co., Ltd, Tokyo), and specific rotations on a Jasco Dip-181 polarimeter (Jasco Co., Ltd, Tokyo). Elemental analyses were performed at

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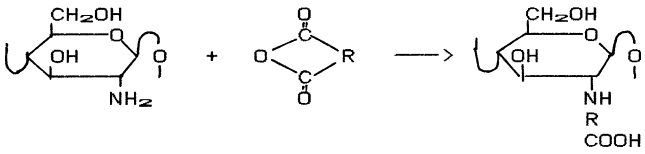

Scheme 1.

the Micro-analytical Center of Kyoto University, Kyoto. The d.s. values for *N*-carboxyacyl groups were calculated on the basis of the C/N ratio in the elemental analysis data. Scanning electron microscopic (SEM) analyses were performed on a scanning electron microscope (S-3000N, Hitachi Ltd, Tokyo).

2.2. Materials

A sample (d.s. 0.00 for NAc, MW 30,000–50,000) of crab shell chitosan was used for the preparation of *N*-(carboxyacyl)chitosan derivatives in a solution state. Chitosan filaments (titer 4.34 denier, tenacity 0.96 gf/denier and elongation 13.0%), which had been wet-spun from a chitosan sample (d.s. 0.17 for NAc, MW 8×10^4–10×10^4) of crab shell chitosan (Hirano, Zhang, Chung, & Kim, 2000), was used as in the present study. Nine intramolecular carboxylic anhydrides were used in the present study: **1**, (2-octen-1-yl)succinic (**2**), citraconic (**3**), **4**, **5**, trimellitic (**6**), 4-methylphthalic (**7**), pyromellitic (**8**) and **9**.

2.3. N-Carboxyacylation in a solution state

A portion (0.16 g) of chitosan was dissolved in 20 ml of 2% aqueous acetic acid, and the solution was diluted with methanol (20 ml). To the solution was added each of **1**–**9** (3–5 mol/Gl cN) (Hirano & Moriyasu, 1981). The mixture was stirred at ca. 50 °C for about 5 min, and allowed to retain at room temperature overnight to give rise to **C1**–**C9** in 69–96% yields.

2.4. N-Carboxyacylation in a filament state

A portion (0.16 g) of chitosan filaments was suspended in methanol (20–30 ml) and each of **1**–**9** (3–5 mol/Gl cN) was added (Hirano et al., 2000). The mixture was stirred at ca. 50 °C for about 5 min, and allowed to retain at room temperature overnight. The filament thus treated was washed with methanol, and air-dried to give rise to **F1**–**F9** in 0.14–0.23 g.

3. Results and discussion

3.1. N-(Carboxyacyl)chitosan derivatives

Chitosan was *N*-carboxyacylated at d.s. 0.39–0.80 by treatment with each of **1**–**9** in a solution of 2% aqueous acetic acid–methanol (1:1, v/v) (Table 1). A hydrogel was produced in the reaction with each of **2** and **9**, a precipitate in those with **4** and **5**, a viscous turbid solution in those with each of **1**, **6** and **8**, and a clear solution in those with each of **3** and **7**. As the results, *N*-(3′-carboxypropen-2′-oyl)chitosan (**C1**) at d.s. 0.68 for N-carboxyacyl, *N*-(3′-carboxy-3′-(octen-2″-yl)propionyl)chitosan (**C2**) at d.s. 0.78, *N*-(3′-carboxy-(1′ or 2′-methyl)propen-2′-oyl)chitosan (**C3**) at d.s. 0.48, *N*-(4′-carboxybutyroyl)chitosan (**C4**) at d.s. 0.75, *N*-(2′-carboxybenzoyl)chitosan (**C5**) at d.s. 0.56, *N*-(2′,4′-dicarboxybenzoyl)chitosan (**C6**) at d.s. 0.39, *N*-(2′-carboxy-4′-methylbenzoyl)chitosan (**C7**) at d.s. 0.40, *N*-(2′,4′,5′-tricarboxybenzoyl)chitosan (**C8**) at d.s. 0.60, and *N*-(3′-carboxypropionyl)chitosan (**C9**) (Yamaguchi et al., 1981) at d.s.

Table 1
Some *N*-(carboxyacyl)chitosan derivatives

Carboxylic anhydrides	*N*-(Carboxyacyl)chitosan	Yield (%)	d.s. for *N*-acyl	$[\alpha]_D^{15}$ (degree) (*c*, 0.3, 1% aq. NaOH)
Maleic	**C1**[a]	92	0.68	−24
(2-Octen-1-yl)succinic	**C2**	86	0.78	n.d.[b]
Citraconic	**C3**	69	0.48	n.d.[b]
Glutaric	**C4**[a]	74	0.75	−12
Phthalic	**C5**[a]	84	0.56	−22
Trimellitic	**C6**	96	0.40	−19
4-Methyl-phthalic	**C7**	73	0.39	−16
Pyromellitic	**C8**	78	0.60	n.d.[b]
Succinic	**C9**[c]	87	0.61	−19

Elemental analytical data are as following: **C2**. *Anal.* Calcd for $[C_6H_{10}O_4N(C_{12}H_{19}O_3)_{0.78}(H)_{0.22}\cdot 1.04H_2O]_n$: C, 53.66; H, 7.89; N, 4.08. Found: C, 53.53; H, 7.84; N, 4.08. **C3**. *Anal.* Calcd for $[C_6H_{10}O_4N(C_5H_5O_3)_{0.48}(H)_{0.52}\cdot 0.69H_2O]_n$: C, 44.37; H, 6.29; N, 6.16. Found: C, 44.49; H, 6.26; N, 6.11. **C6**. *Anal.* Calcd for $[C_6H_{10}O_4N(C_9H_5O_5)_{0.40}(H)_{0.60}\cdot 1.62H_2O]_n$: C, 43.15; H, 5.93; N, 5.24. Found: C, 43.23; H, 5.94; N, 5.24. **C7**. *Anal.* Calcd for $[C_6H_{10}O_4N(C_9H_7O_3)_{0.39}(H)_{0.61}\cdot 1.87H_2O]_n$: C, 44.26; H, 6.62; N, 5.43. Found: C, 44.36; H, 6.20; N, 5.41. **C8**. *Anal.* Calcd for $[C_6H_{10}O_4N(C_{10}H_5O_7)_{0.60}(H)_{0.40}\cdot 1.59H_2O]_n$: C, 43.49; H, 5.01; N, 4.23. Found: C, 43.37; H, 5.37; N, 4.14.

[a] Hirano and Moriyasu (1981).
[b] Not analyzable because of low solubility.
[c] Yamaguchi et al. (1981, 1982).

Table 2
Some *N*-(carboxyacyl)chitosan filaments

Carboxylic anhydrides	*N*-(Carboxyacyl)chitosan filaments	d.s. for[a] *N*-acyl	Titer (denier)	Tenacity (gf/denier)	Elongation (%)
Maleic	**F1**	0.75	4.98	0.37	8.0
(2-Octen-1-yl)succinic	**F2**	0.31	5.06	0.54	10.0
Citraconic	**F3**	0.16	4.66	0.38	9.8
Glutaric	**F4**	0.09	5.10	0.56	8.6
Phthalic	**F5**	0.02	4.09	0.70	7.6
Trimellitic	**F6**[b]	<0.01	5.10	0.90	10.5
4-Methyl-phthalic	**F7**[b]	<0.01	4.95	0.80	11.7
Pyromellitic	**F8**[b]	<0.01	5.20	0.89	8.0
Succinic	**F9**	0.62	5.85	0.63	8.0

Elemental analytical data are as following: **F1**. *Anal.* Calcd for $[C_6H_{10}O_4N(C_2H_3O)_{0.17}(H)_{0.08}(C_4H_3O_3)_{0.75}\cdot 0.75H_2O]_n$: C, 43.94; H, 5.62; N, 5.49. Found: C, 43.99; H, 6.01; N, 5.48. **F2**. *Anal.* Calcd for $[C_6H_{10}O_4N(C_2H_3O)_{0.17}(C_{12}H_{19}O_3)_{0.31}(H)_{0.52}\cdot 0.90H_2O]_n$: C, 48.40; H, 7.50; N, 5.61. Found: C, 48.33; H, 7.67; N, 5.55. **F3**. *Anal.* Calcd for $[C_6H_{10}O_4N(C_2H_3O)_{0.17}(C_5H_5O_3)_{0.16}(H)_{0.67}\cdot 1.77H_2O]_n$: C, 39.32; H, 7.12; N, 6.42. Found: C, 39.57; H, 6.53; N, 6.50. **F4**. *Anal.* Calcd for $[C_6H_{10}O_4N(C_2H_3O)_{0.17}(C_5H_7O_3)_{0.09}(H)_{0.74}\cdot 1.04H_2O]_n$: C, 41.40; H, 7.12; N, 7.06. Found: C, 41.03; H, 6.80; N, 7.17. **F5**. *Anal.* Calcd for $[C_6H_{10}O_4N(C_2H_3O)_{0.17}(C_8H_5O_3)_{0.02}(H)_{0.81}\cdot 1.05H_2O]_n$: C, 41.05; H, 7.12; N, 7.37. Found: C, 41.04; H, 6.84; N, 7.41. **F9**. *Anal.* Calcd for $[C_6H_{10}O_4N(C_2H_3O)_{0.17}(C_4H_5O_3)_{0.62}(H)_{0.21}\cdot 0.78H_2O]_n$: C, 43.36; H, 6.30; N, 5.73. Found: C, 43.28; H, 6.42; N, 5.72.

[a] Excluded d.s. 0.17 for NAc present in the original chitosan filaments.

[b] No N-carboxyacylation occurred as examined by the elemental analyses and the FTIR spectral analyses.

0.80 were isolated is 69–96% yields. The structure of **C1**–**C9** was confirmed by absorptions at 1719–1734 cm^{-1} (COOH), 1630–1653 cm^{-1} and 1541–1570 cm^{-1} (C=O and NH), and by absorptions at 834 cm^{-1} (1,2,4-substituent) for **C6**, 821 cm^{-1} (1,2,4-substituent) for **C7** and 771 cm^{-1} (ortho-substituent) for **C8** in the FTIR spectra. **C1**, **C4**–**C7**, and **C9** (d.s. 0.87) were soluble in water and 1% aqueous sodium hydroxide solution, but **C2**, **C3** and **C8** (d.s. 0.60) were insoluble in these solvents.

3.2. *N*-(Carboxyacyl)chitosan filaments

The d.s. for *N*-carboxyacyl groups were at 0.31–0.75 in **F1**, **F2**, and **F9**, 0.16 in **F3**, 0.08 in **F4**, 0.02 in **5**, and <0.01 in **F6**, **F7**, and **F8**, respectively, (Table 2). Filament **F1** (d.s. 0.75) and **F9** (d.s. 0.62) (Yamaguchi et al., 1981) were soluble in 1% aqueous sodium hydroxide solution, **F2** (d.s. 0.31) was swelled in 1% aqueous NaOH solution, but **F3** (d.s. 0.16), **F4** (d.s. 0.09) and **F5** (d.s. 0.02) were

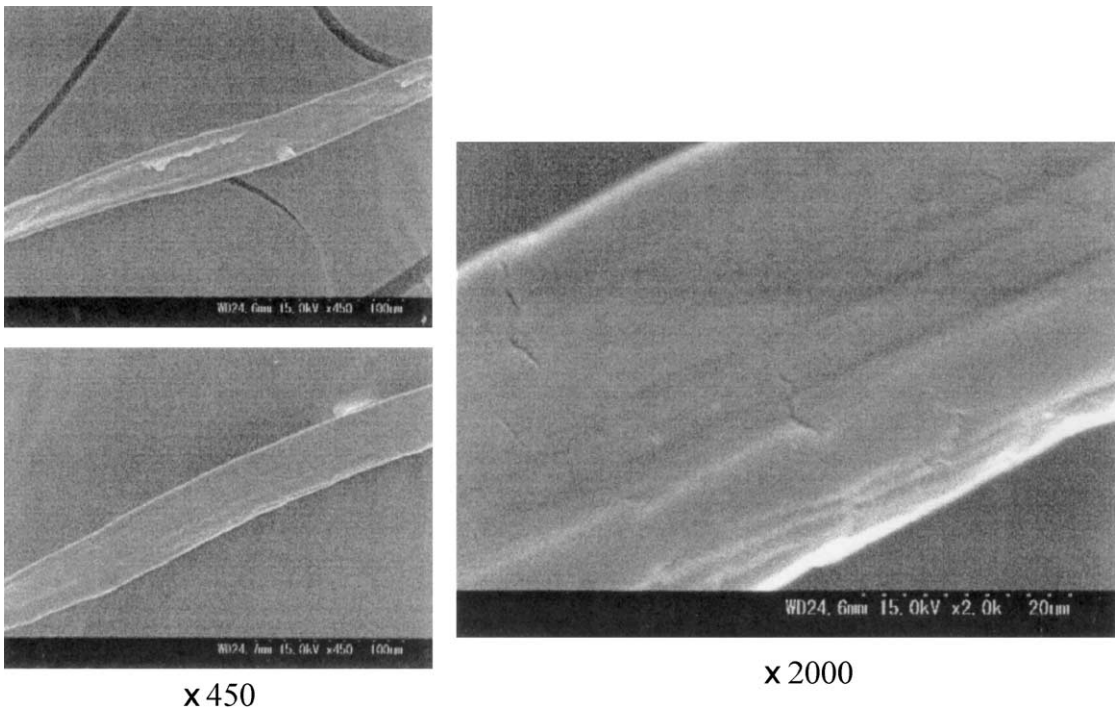

Fig. 1. Scanning electron microscopic (SEM) photographs on the surface of *N*-(3′-carboxypropen-2′-oyl)chitosan filaments (**F1**, 42 μm in diameter, d.s. 0.75 for *N*-carboxyacyl).

Table 3
The diameter, titer and apparent density of some *N*-(carboxyacyl)chitosan filaments

Filament	Filament diameter (μm)	Titer (denier)	Apparent density (denier/μm in filament diameter)
F1	42	4.98	0.12
F2	39	5.06	0.13
Chitosan	31	4.35	0.14

insoluble in these solvents. The presence of *N*-carboxyacyl group in **F1**–**F5** and **F9** was detected by absorptions at 1719–1734 cm^{-1} (COOH), 1630–1653 and 1541–1570 cm^{-1} (C=O and NH) in the FTIR spectra, but these absorptions were not detected in the FTIR spectra of **F6**–**F8**. These data indicate the presence of a steric hindrance on the N-carboxyacylation in the suspension of chitosan filaments due to the large molecular structure of **6**–**8** and the dense organization of chitosan filaments.

3.3. SEM analyses and filament organization

A relatively smooth surface was observed with **F1** (42 μm in filament diameter) as examined by SEM (Fig. 1), and the surface pattern was essentially similar to that of **F2** (39 μm in filament diameter). A scaly pattern on the surface of the original chitosan filaments (Hirano et al., 1999) faded on the N-carboxyacylation. The apparent density calculated as denier/μm in filament diameter is 0.12 for **F1** and 0.13 for **F2**, and these values are slightly lower than 0.14 for the original chitosan filaments (Table 3). The N-carboxyacylation of chitosan filament resulted in a slight increase in the filament diameter but in a decrease in the filament density.

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