Clay Montmorillonite-Catalyzed Aldol Reactions of Silyl Ketene Acetals with Carbonyl Compounds

Makoto ONAKA,* Ryosuke OHNO, Motomitsu KAWAI, and Yusuke IZUMI
Department of Synthetic Chemistry, Faculty of Engineering, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464
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Synopsis. Al^{3+} ion-exchanged montmorillonite efficiently catalyzes the aldol reactions of silyl ketene acetals with carbonyl compounds and acetals. The optimum preparation of the effective montmorillonite catalyst is described.

The use of silicon reagents in organic synthesis has been expanding rapidly in recent years.[1] During the course of our investigation on the application of solid acids as efficient catalysts to carbon-carbon bond formation reactions in a liquid phase, we discovered that the reactions of allylic silanes[2] and silyl enol ethers[3] with aldehydes and acetals are catalyzed by clay montmorillonite to afford the corresponding adducts in high yields. We describe herein catalytic efficiency of Al^{3+} ion-exchanged montmorillonite (Al-Mont) for aldol reactions of silyl ketene acetals (1-alkoxy-1-silyloxy-1-alkenes) with carbonyl compounds, and also the optimum preparation of the effective Al-Mont catalyst.

The cross-aldol reactions of silyl ketene acetals with aldehydes and acetals are generally conducted in the presence of a stoichiometric amount of various Lewis acids.[4,5] Recently the use of effective homogeneous catalysts such as Ph_3CClO_4,[6] Me_2AlCl,[7] and ZnX_2[8] was reported.

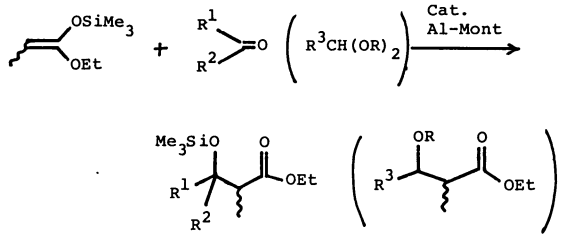
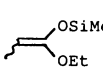
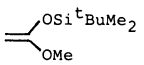
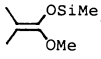


Table 1 summarizes reactions of 1-ethoxy-1-[(trimethylsilyl)oxy]propene with carbonyl compounds and acetals catalyzed by Al^{3+}-montmorillonite.

The Al-Mont-catalyzed aldol reaction of silyl ketene acetals is characterized as follows. 1) Aldehydes and ketones are more reactive than acetals. 2) The catalytic activities of Al-Mont are sensitive to reaction solvent; 1,2-dimethoxyethane (DME) is superior to

Table 1. Al^{3+}-Montmorillonite-Catalyzed Aldol Reactions of Silyl Ketene Acetals with Electrophiles[a]

Run	Silyl ketene acetal	Electrophile	Solv.	Condition: Temp °C	Time min	Yield %	Diastereomer ratio[b]
1	 [c]	$C_5H_{11}CHO$	Toluene	0	60	70	49 : 51
2			CH_2Cl_2	−30	145	75	53 : 47
3			DME	−50	50	88	49 : 51
4[d]		PhCHO	Toluene	−78	120	89	52 : 48[e]
5[d]			CH_2Cl_2	−50	90	91	50 : 50[e]
6[d]			DME	−78	45	95	51 : 49[e]
7		*c*-$C_6H_{11}CHO$	CH_2Cl_2	0	60	78	50 : 50
8			DME	−50	40	93	50 : 50
9[d]		$(C_2H_5)_2CO$	CH_2Cl_2	−78	55	97	—
10		$C_5H_{11}CH(OEt)_2$	Toluene	0	200	68	52 : 48
11			CH_2Cl_2	0	120	56	51 : 49
12			DME	0	30	94	51 : 49
13		$PhCH(OMe)_2$	DME	−50	45	94	50 : 50[f]
14[d]		$C_5H_{11}CHO$	DME	−78	25	86	—
15[d]		$C_5H_{11}CHO$	DME	−50	90	86	—

a) The reaction of the silyl ketene acetal (1 mmol) with an electrophile (0.8 mmol) was carried out in the presence of Al-Mont (0.05 g). b) Determined by GLC. c) E/Z=80 : 20. d) Al-Mont*(0.2 g) was used as a catalyst. e) Determined by NMR on the basis of the integral of the C-3 proton (δ=4.70, 4.98). f) Determined by NMR on the basis of the integral of methoxy protons (δ=3.18, 3.27).

dichloromethane and toluene. 3) Simple distillation, after removal of Al-Mont by filtration, is all that is required to furnish pure products. 4) Aldol products are obtained from aldehyde and ketone in the form of β-trimethylsiloxy esters owing to a non-aqueous work-up procedure, and no formation of α,β-unsaturated esters is observed. 5) In all cases mixtures of diastereomers are produced in good yields but with little or no apparent stereoselectivity.

The reactions of hexanal with silyl ketene acetals derived from acetate and isobutyrate were also catalyzed by Al-Mont catalyst (Runs 14 and 15). In each case the corresponding aldol adduct was readily obtained in the form of β-siloxy ester in high yield.

Clay montmorillonite is easily available and handled. The careful drying pretreatment of the clay is responsible for the attainment of high catalytic activity and good reproducibility in the present reactions because the clay structure changes irreversibly at high temperature.[9]

It should be noted that the present heterogeneous catalyst system of Al-Mont has several advantages and is an alternative to existing homogeneous catalyst systems in aldol reactions by use of silyl ketene acetals.

Experimental

Materials and Measurements. All reactions were performed under nitrogen atmosphere. Solvents were purified by distillation over an appropriate drying agent. Silyl ketene acetals were prepared according to procedures reported in the literature.[10] Aldehydes and ketone were purchased commercially. Acetals were prepared from aldehyde and trialkyl orthoformate by use of Amberlyst-15. Infrared spectra were obtained on a JASCO IRA-2 spectrometer. ^{1}H NMR spectra were recorded in $CDCl_3$ with a Hitachi R-600 spectrometer at 60 MHz. All chemical shifts were reported in relative to tetramethylsilane. GLC was performed with a Shimadzu GC-8A gas chromatograph with a capillary column (PEG-HT, 25 m).

Preparation of Al^{3+} Ion-Exchanged Montmorillonite (Al-Mont). Cation exchange was effected[11] by adding the powdered montmorillonite (100 g) (Purified Na^+ ion-exchanged montmorillonite "Kunipia-F" (cation exchange capacity = 1.19 meq./g) supplied by Kunimine Industries Co. Japan) to an aqueous solution (800 ml) of $Al(NO_3)_3 \cdot 9H_2O$ (150 g, 0.4 mol) with vigorous stirring at r.t. for 2 h. The resultant suspension was filtered on a Büchner funnel by suction. The clay was collected, suspended again in deionized water (500 ml) with stirring at r.t. for 1 h, filtered on a suction funnel, and washed with deionized water (200 ml). The clay collected was again suspended in a mixture of deionized water (200 ml) and methanol (200 ml) with stirring at r.t. for 1 h and filtered. This procedure was repeated twice. The washed clay was pre-dried at 20 °C/1 Torr (1 Torr = 133.322 Pa) for 6 h, and the agglomerated clay was then ground and passed through a 60 mesh screen. The resultant powdered clay was dried at 20 °C/0.5 Torr for 24 h, and stored in a desiccator over anhydrous silica gel until use.

Reaction Procedures. Al^{3+} ion-exchanged montmorillonite (0.05 — 0.2 g) was placed in a 30-ml round-bottomed flask equipped with a magnetic stirrer and dried at 120 °C/0.4 Torr for 3 h. To a suspended Al-Mont in a solvent (3 ml) at −78 °C were added an electrophile (0.8 mmol) in solvent (1 ml) and silyl ketene acetal (1 mmol) in solvent (1 ml) successively. The resulting mixture was stirred vigorously at the temperature shown in Table 1, and the reaction was monitored by TLC or GLC. As work-up, the suspended mixture was passed through a Celite pad and the organic filtrate was evaporated. Aldol products were purified by distillation on a Kugelrohr apparatus and diastereomer ratio of the products was determined by NMR, or by GLC after desilylation of the products.

Ethyl 2-Methyl-3-[(trimethylsilyl)oxy]octanoate. (A mixture of diastereomers): Distilled at 122 °C(bath temp)/0.5 Torr; IR (CCl_4) 1725 cm^{-1} (C=O); ^{1}H NMR ($CDCl_3$) δ = 0.08 (s, CH_3Si), 0.86 (t, J=5.8 Hz, CH_3), 1.06 (d, J=6.8 Hz, $C\underline{H}_3CH$), 1.13 (d, J=6.8 Hz, $C\underline{H}_3CH$), 1.25 (t, J=7.0 Hz, $C\underline{H}_3CH_2O$), 1.00—1.60 (br, $(CH_2)_4$), 2.30—2.75 (m, $CH_3C\underline{H}$), 3.80—4.20 (br, CHOSi), 4.10 (q, J = 7.0 Hz, $CH_3C\underline{H}_2O$).

Ethyl 2-Methyl-3-phenyl-3-[(trimethylsilyl)oxy]propanoate. (A mixture of diastereomers): Distilled at 125 °C(bath temp)/0.3 Torr; IR (CCl_4) 1720 cm^{-1} (C=O); ^{1}H NMR ($CDCl_3$) δ = −0.05 (s, CH_3Si), 0.02 (s, CH_3Si), 0.85 (d, J=7.0 Hz, CH_3), 1.15 (d, J=7.2 Hz, CH_3), 1.09 (t, J= 7.2 Hz, CH_3), 1.28 (t, J=7.2 Hz, CH_3), 2.40 — 3.00 (m, $C\underline{H}CH_3$), 3.98 (q, J=7.2 Hz, CH_2), 4.16 (q, J=7.2 Hz, CH_2), 4.70 (d, J=9.6 Hz, CHOSi), 4.98 (d, J = 7.0 Hz, CHOSi), 7.20—7.40 (br, Ph).

Ethyl 3-Cyclohexyl-2-methyl-3-[(trimethylsilyl)oxy]propanoate. (A mixture of diastereomers): Distilled at 128 °C(bath temp)/0.6 Torr; IR (CCl_4) 1725 cm^{-1} (C=O); ^{1}H NMR ($CDCl_3$) δ=0.00 (s, CH_3Si), 0.90—2.00 (br, cyclohexyl), 0.97 (d, J=7.8 Hz, $C\underline{H}_3CH$), 1.03 (d, J=6.4 Hz, $C\underline{H}_3CH$), 1.18 (t, J=7.4 Hz, CH_3), 2.30—2.85 (m, $C\underline{H}CH_3$), 3.50—3.85 (br, CHOSi), 4.07 (q, J=7.4 Hz, CH_2).

Ethyl 3-Ethyl-2-methyl-3-[(trimethylsilyl)oxy]pentanoate. Distilled at 130 °C(bath temp)/38 Torr; IR (CCl_4) 1730 cm^{-1} (C=O); ^{1}H NMR ($CDCl_3$) δ= 0.02 (s, CH_3Si), 0.78 (t, J=6.8 Hz, CH_3), 1.03 (d, J=6.8 Hz, $C\underline{H}_3CH$), 1.18 (t, J=7.2 Hz, $C\underline{H}_3CH_2O$), 1.44 (q, J=6.8 Hz, CH_2), 2.55 (q, J=6.8 Hz, CH), 4.05 (q, J=7.2 Hz, $CH_3C\underline{H}_2O$).

Ethyl 3-Ethoxy-2-methyloctanoate. (A mixture of diastereomers): Distilled at 107 °C(bath temp)/0.3 Torr; IR (CCl_4) 1730 cm^{-1} (C=O); ^{1}H NMR ($CDCl_3$) δ=0.83 (t, J= 6.0 Hz, CH_3) 1.02 (d, J=7.2 Hz, $C\underline{H}_3CH$), 1.10 (d, J=7.2 Hz, $C\underline{H}_3CH$), 1.20 (t, J=6.8 Hz, $C\underline{H}_3CH_2O$, $C\underline{H}_3CH_2OCO$), 0.95—1.55 (br, $(CH_2)_4$), 2.35—2.95 (m, $CH_3C\underline{H}$), 3.47 (q, J =6.8 Hz, $CH_3C\underline{H}_2O$), 3.30−3.75 (br, CHOEt), 4.10 (q, J= 6.8 Hz, $CH_3C\underline{H}_2OCO$).

Ethyl 3-Methoxy-2-methyl-3-phenylpropanoate. (A mixture of diastereomers): Distilled at 130 °C(bath temp)/0.5 Torr; IR (CCl_4) 1720 cm^{-1} (C=O); ^{1}H NMR ($CDCl_3$) δ=0.88 (d, J = 6.6 Hz, $C\underline{H}_3CH$), 1.14 (d, J=6.4 Hz, $C\underline{H}_3CH$), 1.30 (t, J=7.0 Hz, CH_3), 2.45—2.95 (m, $C\underline{H}CH_3$), 3.18 (s, CH_3O), 3.27 (s, CH_3O), 4.02 (q, J=7.0 Hz, $CH_3C\underline{H}_2O$), 4.26 (d, J=6.8 Hz, $C\underline{H}OCH_3$), 4.45 (d, J=6.8 Hz, $C\underline{H}OCH_3$), 7.20—7.60 (br, Ph).

Methyl 3-[(*t*-Butyldimethylsilyl)oxy]octanoate. Distilled at 127 °C(bath temp)/0.6 Torr; IR (CCl_4) 1735 cm^{-1} (C=O); ^{1}H NMR ($CDCl_3$) δ = −0.03 (s, CH_3Si), −0.01 (s, CH_3Si), 0.80 (s, $(CH_3)_3C$), 0.70—1.00 (br, CH_3), 1.00—1.70 (br, $(CH_2)_4$), 2.39 (d, J=6.6 Hz, CH_2CO_2), 3.61 (s, CH_3O), 3.80—4.25 (br, CHOSi).

Methyl 2,2-Dimethyl-3-[(trimethylsilyl)oxy]octanoate. Distilled at 120 °C(bath temp)/0.4 Torr; IR (CCl_4) 1730 cm^{-1} (C=O); ^{1}H NMR ($CDCl_3$) δ=0.04 (s, CH_3Si), 0.75—0.95 (br, CH_3), 1.02 (s, CH_3), 1.09 (s, CH_3), 1.10—1.55 (br, $(CH_2)_4$), 3.62 (s, CH_3O), 3.70—4.05 (br, CHOSi).

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