Poly(vinyl chloroformate) and derivatives: 3. Chemical modification of poly(vinyl chloroformate)

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The chemical modification of poly(vinyl chloroformate) with compounds containing labile hydrogen atoms like amines, alcohols and phenols as well as with potassium cyanide has been investigated. Convenient conditions have been found in order to obtain soluble modified polymers with good substitution yields.

Keywords Chemical modification; chloroformates; carbamates; carbonates; cyanoformates; characterization

INTRODUCTION

The chemical modification of functional polymers has been extensively studied during the last decade[1]. Polymers of potential biomedical interest have been prepared by reaction of pharmaceuticals like quinine, histamine, cholesterol and testosterone with polyisoprenes or polybutadienes, containing chloroformate groups as terminal or side groups[2-6]. However, the yields of these reactions are quite low ($<40\%$).

However, it has been shown that poly(vinylchloroformate) (PVOCCl) can react with compounds containing labile hydrogen atoms like alcohols, phenols and amines[7]. Reactions have been carried out by immersing the polymer films in aqueous or organic solutions of the reagent. Generally, hydrolysis takes place besides chlorine substitution as in the case of the reaction of PVOCCl with aqueous ammonium hydroxide or with a 1% phenol solution in pyridine. Primary alcohols were found to react slowly leading to poly(vinyl carbonates) whereas primary and secondary amines reacted readily in cyclohexane to give poly(vinyl carbamates). Other derivatives like saccharin, *p*-phenylcarbamide, glucose and sucrose were tried but these led to crosslinked polymers free from chlorine and containing from 20 to 30% of substituents.

Since we were able to prepare well-defined high molecular weight PVOCCl in quantitative yields[8-11], we tried to find convenient conditions for the reaction of some compounds containing labile hydrogen atoms with PVOCCl in order to avoid degradation and to obtain soluble modified polymers with a good yield of substitution[8,10,11]. The results concerning the chemical modification of PVOCCl by amines, alcohols, phenols and potassium cyanide are presented in this paper.

EXPERIMENTAL

Preparation of PVOCCl samples has been described in previous papers[8-11]. Alcohols, phenols, amines, and KCN were commercial products used without special purification. Amines were redistilled under nitrogen just before use. Acetonitrile (ACN) as well as dicyclohexyl-18 crown-6 (Aldrich) were used without purification. Traces of methanol were removed from methylene chlorine and THF was distilled on sodium cuttings under nitrogen before use.

In a typical experiment, the substituent (7.5 mmol) in 20 ml of solvent (ACN or CH_2Cl_2) was added dropwise, under nitrogen, to a vigorously stirred PVOCCl solution (5 mmol in 30 ml of solvent) containing 10 mmol of HCl scavenger (Na_2CO_3 or K_2CO_3). When pyridine or triethylamine were used as HCl scavengers, their solutions (10 mmol in 20 ml of solvent) were added dropwise together with the substituent. At the end of the reaction, the mixture was filtered at room temperature. The polymer was recovered by precipitation in petroleum ether or in ethanol in order to eliminate the quaternary ammonium salts. It was then purified by dissolving it in THF or methylene chloride and reprecipitating it in petroleum ether and finally dried under high vacuum.

The composition of the modified polymers was determined from the elemental analysis of the remaining chlorine and carbon or nitrogen according to the substituent. Polymers were analysed by i.r. spectroscopy with a Perkin Elmer 577 apparatus and by ^1H and ^{13}C n.m.r. with a Jeol C-60 HL, a Varian HA-100 and a Cameca 250 spectrometer.

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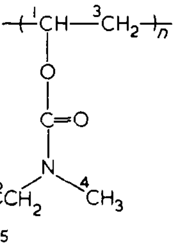
Table 1 Reaction of amines with PVOCCl ([amine]/[Cl] = 1.5; [HCl scavenger]/[Cl] = 2)

Run	Substituent	Solvent	HCl scavenger	Temperature (°C)	Time (h)	Degree of substitution (%)
1	$n\text{–}C_4H_9NH_2$	CH_2Cl_2	Na_2CO_3	42	1	94
2	$n\text{–}C_4H_9NH_2$	CH_2Cl_2	Na_2CO_3	42	2	96
3	$C_6H_5CH_2NHCH_3$	ACN	K_2CO_3[a]	55	3	100
4	$C_6H_5CH_2NHCH_3$	ACN	no	55	3	100
5	$C_6H_5CH_2NHCH_3$	ACN	K_2CO_3	55	0.5	90
6	$C_6H_5CH_2NHCH_3$	ACN	K_2CO_3	42	2	93
7	$C_6H_5CH_2NHCH_3$	CH_2Cl_2	K_2CO_3	40	3	100
8	$C_6H_5CH_2NHCH_3$	CH_2Cl_2	K_2CO_3	40	2.25	97
9	$C_6H_5CH_2NHCH_3$	CH_2Cl_2	K_2CO_3	40	1.5	93
10	$C_2H_5NHCH_2CH_2OH$	CH_2Cl_2	Na_2CO_3	42	2	84
11	$C_2H_5NHCH_2CH_2OH$	CH_2Cl_2	Na_2CO_3	42	4	82
12	$H_2NCH_2COOC_2H_5$, HCl[b]	CH_2Cl_2	$(C_2H_5)_3N$	40	2	95
13	$H_2NCH_2COOHC_2H_5$, HCl[b]	CH_2Cl_2	$(C_2H_5)_3N$	40	3	100

[a] Dicyclohexyl-18 crown-6 added: 1.5 mol % of the chlorine content of PVOCCl
[b] [amine]/[Cl] = 1.2

Table 2 Chemical shifts (ppm from HMDS) of carbon atoms for poly(vinyl *N*-methylbenzylcarbamate) in $C_6H_3Cl_3$ at 110°C

–CH– (1)	–CH$_2$– (2)	–CH$_2$– (3)	–CH$_3$ (4)
68.2*i* 67.8*h* 67.5*s*	51.0	38.8*r* 38.4*m*	32.0



RESULTS AND DISCUSSION

Reaction with amines

PVOCCl in ACN or in methylene chloride solutions was allowed to react with n-butylamine, *N*-methylbenzylamine, 2(ethylamino) ethanol and glycine ethylester. The results are shown in *Table 1*. Alkali carbonates were used as HCl scavengers since their excellent efficiency has been demonstrated for the reaction of amines with chloroformates[12]. Some degradation of polyvinylcarbamate by HCl can occur if no scavenger is used. Addition of a small amount of crown-ether is not necessary for this type of reaction (runs 3 and 7). Generally, some quaternary ammonium salt is formed since the amine is added in excess with respect to the chloroformate functions. Triethylamine was found to be a convenient HCl scavenger in the case of glycine ethylester.

Reaction time, temperature and solvent were varied in the case of *N*-methylbenzylamine. In a general manner, it is preferable to operate in methylene chloride at a temperature not higher than 40°C, especially with very reactive substituents in order to avoid degradation of the polymer. Most of the chemical modifications were quantitative after 3 h reaction.

Primary amines reacted as efficiently as secondary amines. Moreover, in the case of ethylethanolamine, the reaction occurs selectively with the amine group as shown by the i.r. spectrum of the modified polymer. If a solvent more polar than CH_2Cl_2 was used, i.e. acetone or ACN, a cross-linked polymer was obtained.

The i.r. as well as the ^1H and ^{13}C n.m.r. spectra of PVOCCl modified by *N*-butylamine in 96% yield (run 2) were similar to those of the polymer obtained by free-radical polymerization of the corresponding VOCCl derivative[10,11].

The characteristic bands of the i.r. spectrum of PVOCCl quantitatively modified by *N*-methylbenzylamine are located at 1690 cm^{-1} (vs), ν(C=O); 1590 and 1440 cm^{-1} (m), ν(C=C$_{ar}$); 1120 cm^{-1} (s), ν(C–N) and 1220 cm^{-1} (vs), ν(O–C). The ^1H n.m.r. spectrum (CD_3COCD_3, 20°C, 60 MHz) shows five peaks at 2.08 ppm (methylene protons of the chain); 2.73 ppm (methyl protons of the carbon close to the nitrogen); 4.4 ppm (methylene protons of the carbon close to the nitrogen); 5.05 ppm (methine protons of the chain) and 7.3 ppm (aromatic protons) in the expected ratio 2/3/2/1/5. The ^{13}C spectrum of this polymer was recorded at 62.9 MHz in 1,2,4-trichlorobenzene at 110°C. Assignments and chemical shifts (from 0 to 70 ppm) of the different carbons are given in *Table 2*. As in the case of PVOCCl, polyvinylcarbamates and poly(vinyl phenyl carbonate) previously studied, the tertiary carbon of the chain is sensitive to triad effects. The methylene carbon of the chain is sensitive to diad effects and the highest peak can be attributed to racemic diads since this polymer is atactic. However it has not been possible to determine the percentages of different triads and diads with accuracy.

It should be mentioned here that direct measurements of PVOCCl molecular weights are difficult since the chloroformate groups are very polar and reactive. The quantitative modification of PVOCCl by *N*-methylbenzylamine leads to a polymer which is soluble and stable in toluene and in THF. Thus it is possible to measure its molecular weight by osmometry and by g.p.c., and to deduce that of the starting PVOCCl[8,10,11].

The i.r. spectrum of PVOCCl modified by 2(ethylamino) ethanol in 84% yield shows a shift of the carbonyl band from 1770 cm^{-1} to 1695 cm^{-1} which is characteristic of a carbonyl band of a carbamate function. If the OH group had reacted with the chloroformate function, the carbonyl band of the resulting carbonate function would have been located at 1750–1740 cm^{-1}. The other absorption bands are at 3380 cm^{-1} (vs) and

Table 3 Chemical shifts (ppm from TMS) of carbon atoms for PVOCCl modified by glycine ethyl ester in 95% yield, in CD_2Cl_2 at 20°C

$>$C=O (1)	$>$C=O (2)	–CH– (3)	$–CH_2–$ (4)	$–CH_2–$ (5)	$–CH_2–$ (6)	$–CH_3$ (7)
171.0	156.7	69.6	61.8	43.1	38.8	14.8

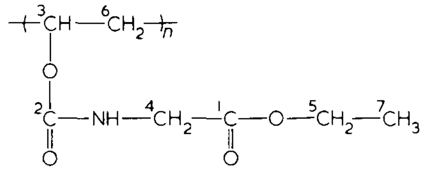


Table 4 Reaction of alcohols and phenols with PVOCCl ([ROH]/[Cl] = 1.5; [HCl scavenger]/[Cl] = 2)

Run	Substituent	Solvent	HCl scavenger	Temperature (°C)	Time (h)	Degree of substitution[a] (%)
14	$NO_2C_6H_4OH$	CH_2Cl_2	K_2CO_3[b]	40	2	23
15	C_6H_5OH	CH_2Cl_2	pyridine	–10	3	88
16	$CH_3OC_6H_4CH_2OH$	CH_2Cl_2	pyridine	0	3	93
17	quinine	THF	K_2CO_3[b]	20	1.25	45

[a] Determined from the chlorine and carbon contents in runs 15 and 16 and from the chlorine and nitrogen contents in runs 14 and 17
[b] With dicyclohexyl-18 crown-6: 1.5 mol % of the chlorine content of PVOCCl

1070 cm^{-1} (m), ν(OH); 1420 cm^{-1} (s), ν(C–N); 1270 cm^{-1} (m), ν(O–C) and 1470 cm^{-1} (m), ν(CH_3). The i.r. spectrum of PVOCCl quantitatively modified by glycine ethylester displays a large carbonyl band at 1725 cm^{-1} which corresponds to the superposition of the two carbonyl bands of the carbamate and of the ester groups. The C–Cl band of PVOCCl at 780 cm^{-1} has completely disappeared. The other characteristic bands are at 3360 cm^{-1} (vs) and 1530 cm^{-1} (s), ν(NH); 1210 cm^{-1} (s), ν(O–C ester); 1280 cm^{-1} (s), ν(O–C carbamate) and 1370 cm^{-1} (m), ν(CH_3). The ^{13}C n.m.r. spectrum of this polymer recorded at 15.1 MHz in CD_2Cl_2 at 20°C affords a confirmation of the structure. Assignments and chemical shifts of the different carbons are given in *Table 3*. The methine carbon of the chain is not stereosensitive, contrary to that of PVOCCl for which a triplet was observed on a spectrum recorded in similar conditions (15.1 MHz, CD_3COCD_3, 30°C)[10,11].

Reaction with phenols and alcohols

Phenols and alcohols are less reactive than amines towards organic chloroformates. Faster reactions and better yields are usually ensured if bases like sodium hydroxide, tertiary amines of pyridine are used to react with the hydrogen chloride which is formed[13]. Pyridine was chosen as the HCl scavenger in the case of the reactions of PVOCCl with phenol and with 4-methoxybenzyl alcohol. The results are shown in *Table 4*. It was necessary to add pyridine dropwise to the PVOCCl solution together with the substituent and to operate at low temperature to avoid polymer precipitation. Two types of degradation of the complex formed between pyridine and chloroformate groups could occur leading to the formation of a double bond and/or a secondary chloride (i.e. vinyl chloride unit)[14].

It was possible to modify PVOCCl with phenol and to obtain a soluble polymer containing 88% of vinyl phenyl carbonate units (run 15). A high yield of substitution was also obtained in the case of 4-methoxybenzylalcohol (93%). Reaction of PVOCCl with *p*-nitrophenol led to a crosslinked material at low temperature in the presence of pyridine whereas a soluble polymer was obtained with CO_3K_2 as HCl scavenger. However, the degree of substitution was not very high in these conditions (23%). An experiment was conducted with quinine and led to a crosslinked polymer containing 45% of quinine units. One ought to try other conditions in order to obtain a soluble polymer and to increase the degree of substitution with this system. Work to this effect is in progress.

The i.r. spectrum of PVOCCl modified by phenol in 88% yield is the same as that of poly(phenyl vinyl carbonate) prepared by polymerization of VOCOPh[10,11]. No hydroxyl band could be detected contrary to the findings of Schaefgen[7] who observed an important hydrolysis when a PVOCCl film was allowed to react for 3 h at room temperature with a 1% solution of phenol in pyridine. The characteristic i.r. bands of PVOCCl modified by 4-methoxybenzylalcohol with 93% yield are located at 1735 cm^{-1} (vs), ν(C=O); 1605 cm^{-1} (vs), 1580 cm^{-1} (m), 1505 cm^{-1} (vs) and 1450 cm^{-1} (s), ν(C=C); 1020 cm^{-1} (s); ν(CH_2–O) and 1370 cm^{-1} (w), ν(CH_3–O). A comparison between the i.r. spectrum of quinine and that of the PVOCCl modified by quinine showed the presence of a carbonyl band at 1730 cm^{-1} and of an O–C band at 1250 cm^{-1} which are characteristic of the carbonate function formed by the reaction of a secondary alcohol with a chloroformate group.

Reaction with potassium cyanide

Poly(vinyl cyanoformate) (PVOCCN) was prepared by Schaefgen[7] from vinyl cyanoformate and tri-n-butylboron at –80°C. However, even in these conditions, only 3 to 5% yields of a low molecular-weight product were obtained. Cyanoformates can be easily prepared by reaction of chloroformates with KCN, using phase transfer catalysis[15]. Moreover, this method has been

Table 5 Reaction of KCN with PVOCCl ([KCN]/[Cl] = 1.5)

Runs	Solvent	Catalyst (mol %)[a]	Temperature (°C)	Time (h)	Degree of substitution (%)
18	ACN	–	30	2.5	2
19	CH_2Cl_2	DCHE (0.5)	20	24	21
20	CH_2Cl_2	DCHE (5.0)	20	5	29
21	ACN	DCHE (1.1)	30	3	74
22	ACN	DCHE (2.2)	20	3	79
23	ACN	DCHE (2.8)	40	3	80

[a] DCHE = dicyclohexyl-18 crown-6, mol % of the chlorine content of PVOCCl

successfully applied to the chemical modification of chloromethylated polystyrene by NaCN[16]. We tried to prepare PVOCCN by reaction of KCN with PVOCCl, using dicyclohexyl-18 crown-6 as phase transfer catalyst. The results are indicated in *Table 5*. The degree of substitution was determined from the chlorine and nitrogen contents of the polymer and was quite low for experiments made in methylene chloride. The use of a crown ether is necessary for this type of reaction even in a more polar solvent such as ACN. High degrees of substitution were obtained in acetonitrile and the most convenient temperature was 20°C since some degradation was observed above it.

The characteristic i.r. bands of PVOCCl modified by KCN with 79% yield (run 22) are located at 1735 cm^{-1} (vs), ν(C=O); 1240 cm^{-1} (vs), ν(O–C) and 2220 cm^{-1} (m), ν(C≡N).

In conclusion, convenient conditions have been found which avoid degradation and hydrolysis and give soluble modified polymers in good yields for the reactions of PVOCCl with primary and secondary amines, phenols, primary alcohols and KCN. It is thus possible to prepare a large variety of new polymers by reaction of different functional molecules with PVOCCl as well as with copolymers containing chloroformate side groups. Further work in this field is in progress.

REFERENCES

1 For a review, see for example: Hodge, P. and Sherrington, D. C. 'Polymer-supported Reactions in Organic Synthesis', John Wiley and Sons, New York, 1980

2 Pinazzi, C., Menil, A. and Pleurdeau, A. *J. Polym. Sci., Polym. Lett. Edn.* 1974, **12**, 447 and *Bull. Soc. Chim. Fr.* 1975, 667

3 Pinazzi, C., Rabadeux, J. C., Menil, A. and Pleurdeau, A. *Eur. Polym. J.* 1975, **11**, 841

4 Pinazzi, C., Menil, A., Rabadeux, J. C. and Pleurdeau, A. *J. Polym. Sci., Polym. Symp.* 1975, **52**, 1

5 Pinazzi, C., Rabadeux, J. C. and Pleurdeau, A. *Eur. Polym. J.* 1976, **12**, 5; *Eur. Polym. J.* 1978, **14**, 205 and *J. Polym. Sci., Polym. Chem. Edn.* 1977, **15**, 1319

6 Pinazzi, C., Rabadeux, J. C., Pleurdeau, A., Niviere, P., Paubel, J. P. and Benoit, J. P. *Makromol. Chem.* 1978, **179**, 1699

7 Schaefgen, J. R. *Am. Chem. Soc. Polym. Prepr.* 1967, **8**(1), 723 and *J. Polym. Sci. C*, 1968, **24**, 75

8 Meunier, G., Hémery, P., Senet, J. P. and Boileau, S. *Polym. Bull.* 1979, **1**, 809

9 Boileau, S., Journeau, S. and Meunier, G. Fr. Patent 1980, 80/02651

10 Meunier, G. *Thèse Docteur-Ingénieur*, Paris, 1981

11 Meunier, G., Hémery, P., Boileau, S., Senet, J. P. and Chéradame, H. *Polymer* in press

12 Piteau, M., Senet, J. P. and Vitrant, A. M. Fr. Patent, 1975, 75/25470

13 Matzner, M., Kurkjy, R. P. and Cotter, R. J. *Chem. Rev.* 1964, **64**, 670

14 Hopkins, T. *J. Chem. Soc.* 1920, **117**, 278

15 Childs, M. E. and Weber, W. P. *J. Org. Chem.* 1976, **41**, 3486

16 N'Guyen, T. D. and Boileau, S. *Tetrahedron Lett.* 1979, 2651