

# Mechanical Properties of Paper Sheets Prepared from Carbamoylethylated Wood Pulp

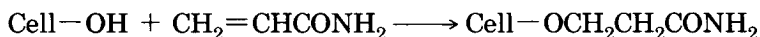
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## Synopsis

Carbamoylethylation of wood pulp was carried out at different conditions including acrylamide concentration, time of impregnation, and medium of the reaction (aqueous and nonaqueous). Mechanical properties of paper sheets prepared from the carbamoylethylated cellulose were examined. Carbamoyethylated paper sheets showed improved double-fold breaking length and burst factor irrespective of the reaction medium. Tear strength remained practically unaltered with aqueous carbamoylethylation but decreased in the case of nonaqueous carbamoylethylation. Water retention value (WRV) decreased by carbamoylethylation especially when the latter was performed in nonaqueous medium.

## INTRODUCTION

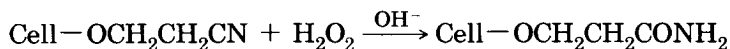
The base catalyzed reaction of cellulose with acrylamide produces carbamoylethylcellulose<sup>1,2</sup> provided that the alkali concentration is kept relatively low:



At higher alkali concentration, the reaction tends to be reversed, and hydrolysis of the amide group takes place. The reaction of cellulose with acrylamide in the presence of 20–40% solution is an excellent method of preparing alkali salts of carboxyethylcellulose.<sup>3,4</sup>

Carbamoylethylation of cellulose proceeds much less readily than the similar reaction of acrylonitrile with cellulose. The efficiency is relatively low, and only low degrees of carbamoylethylation have been obtained. The relative distribution of substituents at the 3-OH groups has been reported to be 1 at C<sub>3</sub>, 9 at C<sub>2</sub>, and 19 at C<sub>6</sub>.<sup>5</sup>

An alternative method of preparing carbamoylethylcellulose is the treatment of cyanoethylcellulose with dilute H<sub>2</sub>O<sub>2</sub> under slightly alkaline conditions<sup>6,7</sup>:



The carbamoylethylated cellulose possesses good retention of strip breaking strength, a slight degree of rot resistance, and substantial heat resistance.<sup>8,9</sup>

The present work is undertaken with a view of studying (a) the susceptibility of wood pulp to carbamoylethylation and (b) some mechanical properties of paper sheets prepared from the carbamoylethylated wood pulp.

## EXPERIMENTAL

Carbamoylethylation of cellulose was conducted in either aqueous medium or in almost nonaqueous medium.<sup>10</sup> Aqueous carbamoylethylation involves impregnating the cellulose sample in aqueous solutions containing acrylamide (5–15%) and sodium hydroxide 4% for different lengths of time. After the desired time the cellulose sample was squeezed to 100% wet pickup and then heated at 125°C for 6 min. At this end, the samples were thoroughly washed, neutralized with hydrochloric acid (0.1*N*), washed again, and air-dried. The use of different concentration of acrylamide (5–15%) was taken as a means to obtain modified cellulose samples having different amounts of carbamoylethyl groups.

Nonaqueous carbamoylethylation of cellulose was performed as follows. The cellulose sample was padded in alcoholic solutions containing different concentration of acrylamide (5–15%) and sodium hydroxide (4%). After the desired time (5 min) the cellulose sample was squeezed to 100% wet pickup and then subjected to heating at 150°C for 5 min. At this end, the samples were rinsed with running water, neutralized with 1% acetic acid, rinsed well with water, and finally air-dried. The amount of carbamoylethyl groups was expressed as percent nitrogen. The latter was determined according to the Kjeldahl method.<sup>11</sup>

**Preparation of Hand Sheets.** The carbamoylethylated wood pulp was beaten to 50 S.R° using Jakro mill. Hand sheets were made from the above pulps according to the Swedish Standard Method (SCA). Strength properties of the produced sheets were tested according to Tappi Standard. In addition, the WRV<sup>12</sup> of the prepared sheets were determined. Wood pulp used in the study is bleached hardwood kraft pulp (B-Nord-Birch) from Sweden.

## RESULTS AND DISCUSSION

Bleached commercial paper grade wood pulp was used as a starting material. Chemical analysis showed that this wood pulp consists of ash 0.28%, lignin 0.96%, pentosan 8.5%, and  $\alpha$ -cellulose 85.16%; time of beating to 50 S.R° for this wood pulp amounted to 22 min.

Figure 1 shows the effect of impregnation time prior to heat treatment (125°C for 6 min) on the extent of aqueous carbamoylethylation of wood pulp. Impregnation was performed at 20°C using a solution consisted of acrylamide (5%) and sodium hydroxide (4%). It is obvious that the extent of carbamoylethylation (expressed as percent nitrogen) increases by increasing the time of impregnation up to 45 min. Further prolongation of this time is accompanied by sharp decrement in the extent of carbamoylethylation.

The enhancement in the extent of the reaction by increasing the impregnation time could be associated with the favorable effect of time on swellability of the cellulose as well as on diffusion and adsorption of acrylamide. This seems to be prevailed over at longer time of impregnation which causes partial hydrolysis of the carbamoylethyl groups to carboxyethyl groups. Besides, partial hydrolysis of acrylamide, if it occurs in the reaction medium, would reduce the reactivity of acrylamide towards cel-

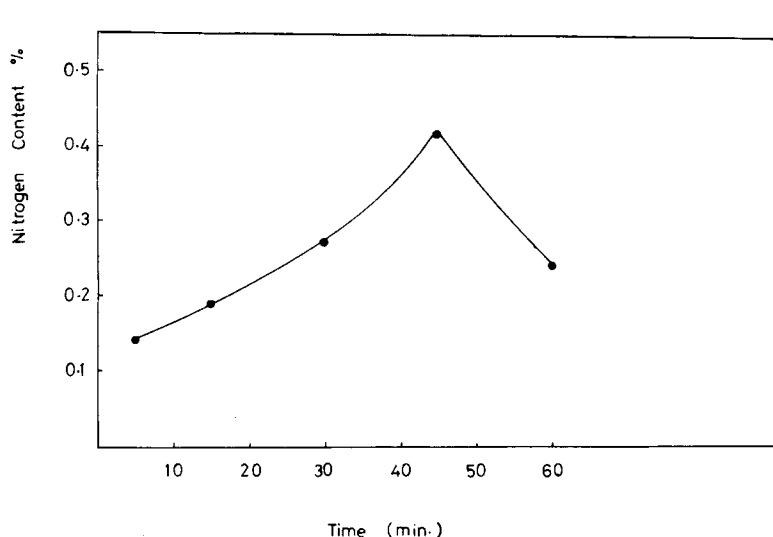


Fig. 1. Effect of impregnation time on the extent of aqueous carbamoylethylation of wood pulp. 5% Acrylamide; 10 g/100 mL solution.

lulose significantly. It is understand that carbamoylethylation reaction is not likely to occur at 20°C.

Figure 2 shows the effect of acrylamide concentration on the extent of carbamoylethylation reaction when the latter was carried out in aqueous and almost nonaqueous media. In both cases the time of impregnation was 5 min, and the operations were performed under conditions detailed in the

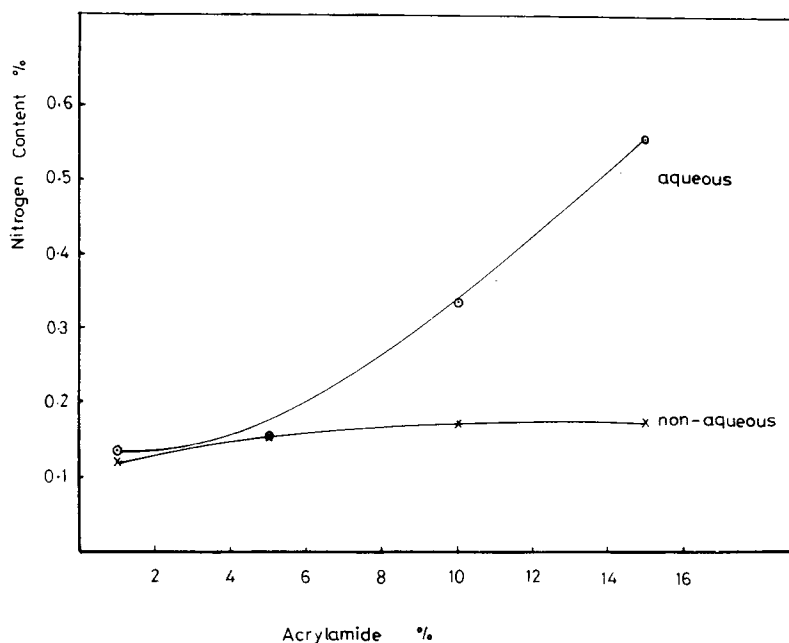


Fig. 2. Effect of acrylamide concentration on aqueous and nonaqueous carbamoylethylation of wood pulp.

TABLE I  
Mechanical Properties of Paper Sheets Prepared from Carbamoylethylated Wood Pulp

Conc of acrylamide (%)	Time of impregnation (min)	Double fold	Tear strength (g)	Burst factor	Breaking length (m)	WRV (%)	Nitrogen content (%)	Time of beating (min)
Aqueous media								
0	0	11	36	18.75	3107.63	210.0	0	22.0
5	5	19	40	22.44	3605.06	204.0	0.144	16.0
5	15	30	36	22.30	3654.64	193.8	0.195	18.3
5	30	31	34	24.20	3998.42	188.4	0.276	18.3
5	45	31	36	28.13	3982.22	185.0	0.418	19.0
5	60	33	36	24.56	4325.19	191.8	0.238	19.0
Aqueous media								
1	5	13	36	19.17	3438.18	183.8	0.142	18.3
10	5	57	36	31.12	4746.83	195.3	0.335	18.45
15	5	122	32	35.34	4414.08	212.0	0.551	18.0
Nonaqueous media								
1	5	18	28	19.2	3605.06	188.2	0.1179	18.0
5	5	13	30	21.89	4289.73	173.2	0.1470	16.0
10	5	18	28	20.27	4568.88	177.5	0.1745	18.3
15	5	14	24	19.93	3967.41	176.1	0.1721	17.0

Experimental section. It is seen that increasing the acrylamide concentration brings about an increase in the extent of the carbamoylethylation reaction. This is observed regardless of the media of carbamoylethylation. Nevertheless, for a given acrylamide concentration, the extent of the reaction is much higher in aqueous than in almost nonaqueous medium, particularly at higher acrylamide concentrations. This reflects the effect of the reaction medium on swellability of cellulose as well as diffusion and adsorption of acrylamide; factors which would certainly influence location and distribution of the carbamoylethyl group in the cellulose structure.

Table I shows the effect of carbamoylethylation of wood pulp under the conditions employed on the mechanical properties of the paper sheets prepared therefrom. It is seen that carbamoylethylation exerts a considerable influence on double fold, tear strength, burst factor, breaking length, and WRV of the paper sheets, being dependent upon the conditions of carbamoylethylation used. Carbamoylethylation causes significant improvement in double fold regardless of the conditions used for carbamoylethylation. The highest improvement in double fold is obtained at 15% aqueous acrylamide solution provided that time of impregnation was 5 min. On the other hand, nonaqueous carbamoylethylation causes marginal improvements in double fold irrespective of the acrylamide concentration used.

Tear strength increases by aqueous carbamoylethylation. The opposite holds true for nonaqueous carbamoylethylation. That is, in nonaqueous media, tear strength decreases.

Burst factor of the prepared sheets shows an increase, which is governed by the condition used. The maximum burst factor is obtained at 15% acrylamide in aqueous solution. In nonaqueous solution burst factor remains almost unaltered.

Table I shows that breaking length of the carbamoylethylated paper sheets is higher than that of untreated paper sheet. This increase in breaking length depends upon the condition of carbamoylethylation. The maximum breaking length is obtained at 10% acrylamide in aqueous and nonaqueous solutions.

The water retention value (WRV) decreases, the magnitude of decrement depends upon the condition of carbamoylethylation used. However, the decrement in WRV is higher in nonaqueous than aqueous media. This suggests that cellulose undergoes much physical changes in aqueous than in nonaqueous medium. Such changes seem to enhance the accessibility of cellulose, which would contribute to WRV. Thus carbamoylethylation imparts hydrophobic characteristic to the cellulose by virtue of the hydrophobic nature of the introduced groups. Table I shows also that carbamoylethylation of wood pulp decreases the time of beating, being dependent upon the conditions used for carbamoylethylation.

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