

Studies on Chemically Modified Cotton Fabrics: Part IV—Physical Properties of DMEU Stripped Hydrocellulose and Hypochlorite Oxycellulose

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Reduction in the degree of polymerization (DPn) of a poplin fabric from 2300 to 350 was carried out by two techniques, viz. (i) alkaline hypochlorite bleaching of mercerised-scoured fabric (MS) to give hypochlorite oxycelluloses, and (ii) acid hydrolysis of mercerised-scoured-peroxide bleached fabric (MSB) to give hydrocelluloses. These were crosslinked with DMEU by the pad-dry-cure technique using $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ as catalyst and further DMEU stripped through urea-phosphoric acid (UPac) hydrolysis. From the study of the strength-abrasion properties of these treated fabrics it was found that (i) the MSB sample undergoes less "total" loss as compared to the MS sample on DMEU crosslinking. However, the MSB sample suffers greater "permanent" loss compared to the MS sample and (ii) hydrocelluloses undergo less "total" and "permanent" losses compared to hypochlorite oxycelluloses at all DPn levels. However, the oxycelluloses possess better strength-abrasion properties after DMEU crosslinking due to their higher values at the unfinished stage as compared to the hydrocelluloses.

The infrared and functional group analyses of two chemically modified cotton fabrics, viz. hydrocellulose and hypochlorite oxycellulose that have undergone various treatments like thermal treatment in the presence of catalyst, DMEU crosslinking and urea-phosphoric acid hydrolysis of unfinished and DMEU finished fabrics, were reported in the preceding part of this series¹. In the present communication, the results of a study on the effect of the above treatments on the resilience and strength-abrasion properties of the two modified fabrics are presented. Attempts have also been made to find out the extent of "permanent" and "temporary" losses that take place during DMEU crosslinking of these two modified fabrics.

Materials and Methods

Materials—The details of preparation of the two chemically modified cotton fabrics and their subsequent treatments are given in the preceding part of this series¹.

Methods—Conditioned and wet wrinkle recovery angles were determined using Monsanto tester². DP rating was assessed by AATCC method using the hand wash and line drying technique³. Tensile strength and elongation at break were determined by ravelled strip method using the principle of constant rate of traverse⁴. Flex abrasion was determined on Stoll's wear tester using 1 lb head load and 4 lb tension load⁵. Tear strength was determined by Elmendorf method⁶.

Results

Unfinished hydrocellulose and hypochlorite oxycellulose—The resilience properties (conditioned WRA, wet WRA and DP rating) of both hydrocellulose

and hypochlorite oxycellulose are not affected by decrease in DPn (Table 1) (Sample A). However, it is seen from Table 2 that the strength-abrasion properties show a progressive decreasing trend with decrease in DPn. The values of strength-abrasion properties in the case of hypochlorite oxycellulose are higher than those for hydrocellulose at any DPn level. Similar findings have been reported earlier⁷. However, at a very low DPn level of around 350 (Samples H₄ and HC₄), both the modified fabrics behave in a different manner from the rest of the series of samples. Hence, in further discussion they are dealt with separately.

Effect of thermal treatment in the presence of catalyst—In resilience properties, both the modified fabrics do not show any change on pad-dry-cure treatment in the presence of 20 g/litre $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ catalyst (Table 1) (Sample B). In respect of strength-abrasion properties, both these modified fabrics retain 86-97% tensile strength, 83-100% elongation at break (showing an increasing trend with decreasing DPn in both the cases) and 80-109% tear strength (Table 2). Thus, the nominal losses in the strength properties of both the modified cotton fabrics are in agreement with those reported by Koudelka⁸ for similar treatment on periodate oxycellulose. In the case of flex abrasion retention, hydrocellulose shows a decreasing trend from 106 to 76% with decrease in DPn, except for sample H₂. On the other hand, in the case of hypochlorite oxycellulose, an increasing trend from 86 to 100% is seen, except for sample HC₂. Thus, thermal treatment in the presence of catalyst has also a deteriorating effect on the abrasion properties of these two fabrics.

Table 1—Nitrogen Fixed and Resilience Properties of Chemically Modified Cotton Fabrics Subjected to Different Treatments

Sample	DPn	Nitrogen fixed, % owf	WRA (W + F) ^o										DP Rating				
			Conditioned					Wet					A	B	C	D	E
			A	B	C	D	E	A	B	C	D	E					
Hydrocellulose (Control)	MSB	2362	0.03	0.05	1.07	—	0.05	182	195	274	181	185	155	168	257	173	160
	H ₁	1418	0.03	0.03	1.09	0.03	0.03	169	173	272	178	173	159	164	259	172	165
	H ₂	745	0.03	0.02	0.77	0.03	0.03	177	180	271	192	176	168	171	256	174	167
	H ₃	567	0.04	0.03	0.95	0.03	0.04	198	195	280	198	196	177	182	266	177	179
	H ₄	355	0.02	0.03	1.04	0.02	0.03	184	171	281	182	165	175	173	260	179	177
Hypochlorite oxycelluloses (Control)	MS	2362	0.03	0.03	1.08	0.03	0.05	189	193	276	176	201	166	168	254	169	167
	HC ₁	1418	0.03	0.02	1.00	0.03	0.03	178	179	274	193	179	172	172	259	172	173
	HC ₂	745	0.03	0.03	1.09	0.03	0.03	180	179	274	200	182	177	175	262	175	179
	HC ₃	567	0.03	0.03	0.94	0.04	0.04	199	197	282	200	198	179	184	261	180	180
	HC ₄	355	0.03	0.03	0.99	0.03	0.04	178	168	282	198	160	175	172	263	180	177

A, Unfinished; B, Catalyst treated; C, DMEU finished; D, UPac hydrolysed; and E, DMEU stripped samples.

Effect of DMEU crosslinking—On DMEU crosslinking (Sample C), the resilience properties improve substantially (Table 1). These values are in the durable-press range and are comparable for both the modified fabrics. The nitrogen fixed of both the fabrics are in the range 0.9–1.1%, which shows that the fixation of DMEU applied is in the range 90–100%. From strength-abrasion properties of both the fabrics given in Table 2, it is seen that on DMEU crosslinking, both the fabrics suffer losses in these properties, as may be seen from their retention values. However, hypochlorite oxycelluloses suffer greater losses in strength-abrasion properties than hydrocelluloses. Even then, it may be borne in mind that this oxycellulose possesses higher strength-abrasion properties after DMEU crosslinking, which can be attributed to the higher order of these properties in the unfinished stage. This is in conformity with our earlier findings⁹.

Effect of urea-phosphoric acid (UPac) hydrolysis—Since UPac hydrolysis is carried out for stripping of DMEU crosslinks from the DMEU finished fabrics, it was thought worthwhile to assess the changes in physical properties that may occur on the two chemically modified fabrics during such a treatment. The strength-abrasion properties of these two fabrics after UPac hydrolysis (Sample D) are given in Table 2. It is evident that in the case of hydrocellulose, the percentage retention values for all the four strength-abrasion tests are in the range 90–100%, except for a few samples showing that this acid treatment has no significant damaging influence on hydrocellulose. Similar observations were made by Jung *et al.*¹⁰ in their study on UPac hydrolysis of unfinished and DMEU finished cotton fabrics. However, in the case of oxycellulose, these values are considerably lower than those for hydrocellulose, especially in the case of tear strength and flex abrasion properties, showing that in the absence of crosslinks, UPac hydrolysis has a high damaging effect on this oxycellulose. This is surprising when one considers the fact that chemical analysis of these two fabrics does not show any significant change either in DPn or functional groups during UPac hydrolysis (Table 2, ref. 1).

Effect of DMEU stripping—As discussed in the preceding part of this series¹, during UPac hydrolysis of the DMEU crosslinked fabrics, all the DMEU crosslinks are removed. This is reflected in the values for fixed nitrogen and resilience properties which are reverted to those for unfinished fabrics (Table 1) (Sample E). In strength-abrasion properties, there is a remarkable regain on DMEU stripping, especially in tensile properties (Table 2) (Samples E vs Sample C). Similar findings have been reported by Jung *et al.*¹⁰ and Segal and Timpa¹¹. However, the

Table 2—Strength-abrasion Properties of Chemically Modified Cotton Fabrics Subjected to Different Treatments

Sample	Tensile strength, % Rtn (W + F) ^o					Elongation at break, % Rtn (W + F) ^o					Tear strength, % Rtn (W + F) ^o					Flex abrasion, % Rtn (W + F) ^o				
	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Hydrocellulose																				
MSB	100	90	72	91	99	100	83	66	83	87	100	99	71	110	80	100	106	40	101	61
(Control)	(57.1)*					(35.0)					(179.7)					(2482)				
H ₁	100	88	68	87	90	100	93	73	77	95	100	81	72	105	88	100	86	34	61	56
	(53.7)					(36.5)					(1656)					(1817)				
H ₂	100	87	75	91	99	100	97	73	92	98	100	80	73	93	83	100	94	42	112	117
	(35.8)					(31.7)					(1221)					(840)				
H ₃	100	95	81	98	95	100	100	86	90	96	100	109	76	116	107	100	76	36	101	86
	(22.8)					(24.0)					(717)					(265)				
H ₄	100	61	76	104	102	100	85	70	94	104	100	57	58	85	75	100	23	9	76	58
	(18.4)					(20.0)					(648)					(118)				
Hypochlorite oxycelluloses																				
MS	100	91	67	95	97	100	83	55	92	89	100	85	62	94	100	100	86	33	79	89
(Control)	(58.3)					(36.0)					(2080)					(3438)				
HC ₁	100	86	70	83	90	100	83	68	87	85	100	91	58	85	86	100	93	37	39	50
	(56.5)					(35.2)					(1936)					(3111)				
HC ₂	100	90	68	79	87	100	90	73	87	89	100	83	61	73	80	100	66	19	46	62
	(42.9)					(31.2)					(1445)					(1713)				
HC ₃	100	98	72	84	87	100	95	71	91	95	100	99	81	101	89	100	100	34	69	103
	(36.0)					(29.6)					(1088)					(845)				
HC ₄	100	82	96	117	111	100	92	58	104	104	100	65	89	110	104	100	54	31	120	131
	(19.0)					(26.0)					(640)					(116)				

A, B, C, D and E have the same significance as in Table 1.

*Figures within parentheses are actual values in the unfinished stage.

regain of tear strength and flex abrasion values is only partial, suggesting that permanent loss in these properties does occur either during DMEU crosslinking or during its removal.

Effect of various treatments on low DPn hydrocellulose and hypochlorite oxycellulose (H₄ and HC₄)—The resilience properties of these two samples follow a similar pattern as in the case of other samples during various treatments, viz. thermal treatment in the presence of catalyst, DMEU crosslinking and UPac hydrolysis of unfinished and DMEU finished samples, except that during DMEU stripping, the conditioned WRA values of these two fabrics are lower than those for unfinished fabrics (Table 1). It is interesting to note that in the case of hypochlorite oxycellulose the reduction in DPn from 560 (Sample HC₃) to 350 (Sample HC₄) brings down the strength-abrasion properties considerably. Consequently, these strength-abrasion values for HC₄ become comparable to those for H₄, unlike in the case of samples with higher DPn values, where the oxycellulose gives higher values than the corresponding hydrocellulose.

During thermal treatment in the presence of MgCl₂·6H₂O (Sample B), there is considerable loss in strength-abrasion properties of both these fabrics unlike in the case of samples with higher DPn values. These severe losses in strength-abrasion properties are not reflected either in DPn values or functional groups, which were reported earlier (Table 1, ref. 1). Probably at this very low DPn level, both these modified cotton fabrics would have reached their minimum load sharing capacity which gets lowered further on subsequent thermal treatment (i.e. brittleness increases substantially) and gives rise to abnormal losses in strength-abrasion properties. This being mainly a physical phenomenon, may not be reflected in either chemical or physico-chemical test methods.

With the introduction of DMEU crosslinks (Sample C), the tensile strength values improve for both the modified fabrics over those for catalyst treated samples (Sample B), showing that the crosslinks impart some "reinforcing effect" at this low DPn level, as suggested by Meyer *et al.*¹². This is reflected to a limited extent in tear strength also. However, in elongation at break and flex abrasion, there is a steep fall for both the modified fabrics, suggesting that the DMEU crosslinks introduced increase the embrittlement of the finished fabrics at the low DPn level.

On UPac hydrolysis (Sample D) in the case of hydrocellulose, except in tensile strength, there is a fall in retention of all the strength-abrasion properties, whereas in the case of hypochlorite oxycellulose, there is an increase in the retention values of all these properties. Thus, this opposing trend of the two modified cotton fabrics at very low DPn levels is all the

more difficult to explain when one considers the fact that there is hardly any change either in the DPn or the functional groups of these two modified fabrics during UPac hydrolysis (Table 2, ref. 1).

On removal of DMEU crosslinks by UPac hydrolysis (Sample E), hypochlorite oxycellulose is able to regain the strength-abrasion properties back to the unfinished level. However, in the case of hydrocellulose, the regain is complete only in the case of tensile properties. In tear strength and flex abrasion, the recovery is only partial. Thus, the two DMEU stripped fabrics at this low DPn level behave in a different manner in comparison to high DPn samples.

Discussion

Performance profile charts—To make a comparative study of the two modified fabrics (having varying and comparable DPn values) undergoing various treatments, viz. thermal treatment in the presence of catalyst, DMEU crosslinking, UPac hydrolysis and DMEU stripping, it was thought worthwhile to use performance profile charts for resilience⁹ and strength-abrasion properties⁷, as reported in our earlier studies. The performance profile chart used in the present study excludes Accelerator weight retention test. This has been done because it was found that this test method gives inconsistent results compared to other strength-abrasion tests, as discussed earlier¹³. The rating scales for resilience and strength-abrasion properties are the same as reported earlier^{7,9}, viz. 0-25 for the resilience properties and 0-40 for the strength-abrasion properties. All the scales are linear. The scores for individual resilience and strength-abrasion properties for each of the samples were read against the rating scales. The values obtained for the two modified fabrics undergoing the above-mentioned treatments were added up and the total scores for resilience and strength-abrasion properties are given in Table 3. In the case of resilience properties, only the scores for DMEU crosslinked samples (Sample D) are reported, since in all other cases there is hardly any change in the resilience properties.

Overall Performance of Hydrocellulose and Hypochlorite Oxycellulose

Unfinished fabrics—For the unfinished fabrics of both the types, the total score of 109 for strength-abrasion properties of MSB (control) comes down to 10.7 as the DPn gets reduced from 2360 to 350 in the case of hydrocelluloses; the corresponding values for hypochlorite oxycellulose are 124.7 and 18.3 for the same range of DPn reduction (Table 3) (Sample A). On comparing these scores for the two modified fabrics it is evident that hypochlorite oxycellulose possesses significantly higher values than those for hy-

Table 3—Changes in DPn and Strength-abrasion Scores Subjected to Different Treatments of Hydrocelluloses and Hypochlorite Oxycelluloses

Sample	DPn					Total score for strength-abrasion properties					"Temporary" loss E-C	"Permanent" loss A-E	"Total" loss A-C	Resilience score C	
	A	B	D	E		A	B	C	D	E					
Hydrocelluloses															
MSB	2362	1979	2277	2520		109.1	97.0	55.6	99.2	87.8	32.2	21.3	53.5	46.6	
(Control)		(-16)*	(-4)	(+7)			(-11)*	(-49)	(-9)	(-20)	(60)†	(40)†	(100)		
H ₁	1418	1303	1293	1437		99.2	82.5	51.3	78.6	81.3	30.0	17.9	47.9	40.3	
		(-7)	(-9)	(+6)			(-17)	(-48)	(-18)	(-18)	(63)	(37)	(100)		
H ₂	745	658	783.6	820		59.1	48.6	28.8	52.0	55.3	26.5	3.8	30.3	45.6	
		(-11)	(+6)	(+9)			(-18)	(-52)	(-12)	(-6)	(87)	(13)	(100)		
H ₃	567	582	502	585		22.3	21.9	8.9	20.8	21.2	12.3	1.1	13.4	45.3	
		(+5)	(-12)	(+3)			(-2)	(-60)	(-7)	(-5)	(92)	(8)	(100)		
H ₄	355	379	317	434		10.7	-6.6	-7.6	7.9	8.6	16.2	2.1	18.3	46.6	
		(+1)	(-11)	(+16)			(-161)	(-171)	(-26)	(-20)	(89)	(11)	(100)		
Hypochlorite oxycelluloses															
MS	2362	2253	2277	1871		124.7	102.2	55.4	109.6	114.4	59.0	10.3	69.3	46.3	
(Control)		(-5)	(-4)	(-21)			(-18)	(-56)	(-12)	(-8)	(85)	(15)	(100)		
HC ₁	1418	1326	1217	1266		117.1	93.3	53.9	80.4	86.1	32.2	31.0	63.2	47.1	
		(-6)	(-14)	(-11)			(-18)	(-54)	(-31)	(-27)	(51)	(49)	(100)		
HC ₂	745	625	666	601		77.1	59.3	30.5	47.9	56.7	26.2	20.4	46.6	47.8	
		(-17)	(-11)	(-19)			(-28)	(-61)	(-38)	(-27)	(56)	(44)	(100)		
HC ₃	567	566	500	492		54.2	51.1	22.8	43.4	41.6	18.8	12.6	31.4	49.6	
		(-3)	(-12)	(-12)			(-6)	(-58)	(-20)	(-23)	(60)	(40)	(100)		
HC ₄	355	312	400	290		18.3	7.5	-1.7	24.0	22.4	24.1	+4.1	20.0	47.6	
		(-15)	(+13)	(-18)			(-59)	(-109)	(+31)	(+22)	—	—	—	—	

*Figures within parentheses represent % changes from respective controls (A).

†Figures within parentheses are % of total loss.

drocellulose, confirming our earlier observations on these two modified fabrics⁷. The behaviour of both the low DPn samples, i.e. H₄ and HC₄, during various treatments is different from those of samples with higher DPn levels; hence they are discussed separately.

Catalyst treated fabrics—The thermal treatment, i.e. pad-dry-cure treatment of the two modified fabrics using 20 g/litre MgCl₂·6H₂O as catalyst, causes a reduction in the total score for strength-abrasion properties of around 20% (Sample B) for all the samples, except H₃ and HC₃. This is also reflected in the reduction of their DPn values. Thus, the molecular degradation of the two modified fabrics does take place during thermal treatment in the presence of catalyst.

DMEU crosslinked fabrics—As expected, on DMEU crosslinking, the total scores for strength-abrasion properties for both the modified fabrics show a steep fall, i.e. 48–61%, which can be attributed to the improvement in the resilience properties of these fabrics. On comparing the two modified fabrics, it is noted that oxycellulose shows slightly higher order of losses due to the fact that it shows a slightly better score for resilience properties as compared to hydrocellulose.

UPac hydrolysis of unfinished and DMEU finished fabrics—During UPac hydrolysis, hypochlorite oxycellulose loses up to about 30% in the total score as compared to about 18% in the case of hydrocellulose. Thus, it is evident that the acid treatment has some deteriorating influence on both the modified fabrics in the absence of crosslinks and this is more pronounced in the case of oxycellulose. It is interesting to observe that on DMEU stripping, hydrocellulose is able to regain the total score for strength-abrasion properties to a better extent than oxycellulose. However, the absolute values of the total score for oxycellulose at all DPn levels are higher than the corresponding values for hydrocellulose.

Overall Performance of Low DPn Samples

In the case of low DPn samples, i.e. H₄ and HC₄, there is severe reduction in their total scores during thermal treatments involving catalyst alone (Sample B) and during DMEU crosslinking (Sample C), which can be attributed mainly to molecular degradation of both the modified fabrics, as explained above. During UPac hydrolysis, hydrocellulose shows a reduction of 26% in its total score, whereas oxycellulose shows a gain of 31%. This trend is again visible during DMEU stripping on both the fabrics. Thus, the role of UPac hydrolysis in the absence and presence of DMEU crosslinks on these low DPn chemically modified fabrics seems divergent, i.e. deteriorating influence in the case of hydrocellulose and reinforcing influence in the case of oxycellulose, which is inexplicable.

Permanent and temporary losses—In crosslinking reactions of cotton fabrics it is well known that

reduction in strength-abrasion properties occurs due to the introduction of crosslinks. Thus, in the present study, severe reduction in the total scores for strength-abrasion properties from the unfinished stage (Sample A) to the DMEU crosslinked stage (Sample C) was obtained. This difference is taken as the "total" loss in the strength-abrasion scores. On removal of DMEU crosslinks, these scores are regained to a great extent, but still these values are below those for the unfinished stage. This difference between the total score for unfinished samples and those for DMEU stripped samples is termed as "permanent" loss, which can be attributed to the molecular degradation of cotton during crosslinking. The difference between the scores for DMEU stripped samples and those for the DMEU crosslinked sample is termed as "temporary" loss, which results from the crosslink embrittlement of the fabrics. Similar analyses of "total" losses, "permanent" losses and "temporary" losses were carried out for formaldehyde crosslinked fabrics by Segal and Timpa¹⁴ and for DMEU and formaldehyde crosslinked fabrics by Meyer *et al.*¹². The "total" loss for hydrocellulose, as seen from Table 3, is in the range 53.5–18.3; for hypochlorite oxycellulose, the range is 69.3–20.0. Thus, oxycellulose suffers greater loss in its total score for strength-abrasion properties as compared to hydrocellulose.

The "permanent" and "temporary" losses calculated as percentages of the respective "total" loss are given in Table 3. It is seen that for the two control fabrics, i.e. MSB for hydrocellulose and MS for hypochlorite oxycellulose, the "total" losses are 53.5 and 69.3 respectively. The lower "total" loss on MSB as compared to MS is in conformity with our earlier findings on the effect of the preparatory process on the strength-abrasion properties of durable-press cotton fabrics, it is interesting to note that in MSB, a ratio of "temporary"/"permanent" loss of 60:40 is observed, whereas the same for MS is 85:15. The higher order of "permanent" loss on MSB may be attributed to the additional processing step undergone by this fabric, i.e. peroxide bleaching. A similar analysis in the case of hydrocellulose shows that the highest DPn sample (H₁) behaves in a similar manner to its control (MSB), while the rest of the samples show the ratio of 90:10 for "temporary"/"permanent" losses. Thus, it appears that lowering of DPn through acid hydrolysis to a value below 1300 imparts greater resistance to permanent loss due to molecular degradation during DMEU crosslinking. In the case of hypochlorite oxycellulose, no such marked differentiation between high and low DPn fabrics is observed. They show a slightly increasing trend with decrease in DPn from 50 to 60% in "temporary" loss. Thus, the ratio of "temporary" to "permanent" loss varies from 50/50 to 60/40.

On comparing the "permanent" losses of hydrocellulose and hypochlorite oxycelluloses, it is seen that the former gives a range of 37-8%, whereas the latter gives 40-50%. This suggests that lowering of DPn through oxidation by alkaline hypochlorite as against acid hydrolysis gives rise to much higher "permanent" losses during DMEU crosslinking by the pad-dry-cure technique using $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ as catalyst. This is also supported by the chemical analysis data (Table 1, ref. 1) wherein the oxycellulose shows significant reduction in DPn and increase in various functional groups for the samples analysed after removing the crosslinks.

Sample HC₄ behaves abnormally as compared to other hydrocelluloses and hypochlorite oxycelluloses. Thus, from a total loss of 20 units, it regains 24.1 units and gives a net gain of 4.1 units on DMEU stripping. The concept of dividing the "total" loss into "temporary" and "permanent" losses, therefore, does not hold good for this sample.

Summary and Conclusions

Reduction in DPn of a poplin fabric from 2300 to 350 was carried out by two techniques, viz. (i) alkaline hypochlorite bleaching of mercerised-scoured fabric (MS) to give hypochlorite oxycelluloses, and (ii) acid hydrolysis of mercerised-scoured-peroxide bleached fabric (MSB) to give hydrocelluloses. These were crosslinked with DMEU by the pad-dry-cure technique using $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ as catalyst and further DMEU stripped through UPac hydrolysis. From the study of the strength-abrasion properties of these two modified fabrics, the following conclusions are drawn.

(1) Mercerised-scoured-peroxide bleached fabric (MSB) undergoes less "total" loss as compared to mercerised-scoured fabric (MS) during DMEU crosslinking. However, the former suffers greater

"permanent" loss as compared to the latter.

(2) Hydrocelluloses undergo less "total" and "permanent" losses as compared to hypochlorite oxycelluloses at all DPn levels. However, the latter possess better strength-abrasion properties after DMEU crosslinking due to their higher values at the unfinished stage.

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