Restaurator, 1997, 51–72
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RESTAURATOR
ISSN 0034-5806

The Effect of Different Strengthening Methods on Different Kinds of Paper

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INTRODUCTION

Within the wide range of means to preserve our cultural heritage stored in archives and libraries, as far as it is endangered by chemical or biological decay, preserving the original format is without doubt the noblest. But, as soon as the originals have suffered decay in an amount that they can no longer be handled as it is necessary for reading, this noblest means is also the most expensive one – possibly with one exception, see below. Generally it must be stated that, if a sheet of paper has reached that state of decay that it can no longer be handled, the only means to preserve it is to combine it with another sheet-shaped object. Any other method, resizing, defined as bathing the sheets in the solution of a film-forming compound or spraying them with such a solution, or graft polymerization or such else, do not really give the necessary stability to a sheet decayed to this extent. Honestly, to use a term that might be construed as somewhat too sharp, the stability effected by these methods is only measurable on sheets not needing to be strengthened.

The methods to combine a sheet of brittle paper with another, a strengthening sheet-shaped object, differ in how this other sheet-shaped object is produced and how it is integrated into the original. The oldest and considered classic, but antiquated method is laminating another paper, mostly Japanese tissue, onto the surfaces of the decayed one using starch paste or methyl cellulose as adhesive. In the variant that a thermoplastic, mostly poly methyl methacrylate[1], is used, this laminating is widely used and possibly indispensable for water sensitive objects, in the case of corrosive ink in an advanced stage, e.g.. To avoid the aesthetic alteration at the surface of the original, the second, the strengthening sheet can be brought into the interior of the decayed paper after having split it[2]. In order to achieve better adaption or to speed up the process, the strengthening sheet can be produced directly for the decayed one and in combination with it, either using fibres for paper, i.e. leafcasting[3], or a plastic monomer for a synthetic coating, i.e. the

Parylene-process[4]. It is discussed that, regarding the cost, this process could possibly compete with microfilming.

Regarding the strengthening effect of the different methods and its ageing stability little information can be found in technical literature. Until now, relevant studies done have been limited to paper splitting[5], even this not taking into consideration the ageing behaviour of sheets treated for strengthening. The object of this study[6] is to get an idea of comparative results of the other methods in question, and mainly of their impact on ageing. We were interested in not only the strengthening effect of the different methods, but also in their impact on the aesthetic appearance. We excluded any resizing methods, for reasons given above, and we excluded the classic lamination with starch paste or methyl cellulose: it is highly inferior to splitting and leafcasting regarding aesthetics and does not give any advantage (with the exception that it needs little equipment). It should be considered to be obsolete.

Another request of our study was to test the different methods not only on new paper or laboratory handsheets, chosen in conservation research because they are well defined, but also on old papers, preferably those really needing to be strengthened or at least near to that state, as they are the usual objects of practical work.

PROJECT

Five different papers were chosen for treatment according to four different strengthening methods, one of them in three variations, and submitted to accelerated ageing. For evaluating the strengthening effect we chose only one, i.e. tensile strength after one defined fold, as it has been proved to be apt just to describe the usability of old papers[7], the more common MIT-folding test being too harsh for really brittle material. We excluded definitely the conventional tensile strength test, as for strong papers it gives the same results as tensile post fold and as it does not give sufficient distinction for weak ones. A totally brittle paper that breaks when simply folded and that therefore can not be handled without a support, can have a tensile strength of, say, 2 or 3 N: the same as a very thin, but flexible and therefore usable paper. We also explicitly abstained from the usual ph checking after treatment and after ageing. All strengthening methods can be done in a way to raise the pH or at least, if it is initially low, they can be combined with one of the usual methods of deacidification. Furthermore, the pH goes down in any way during accelerated ageing. Relevant tables would hardly give any other information than supporting this platitude. To evaluate aesthetics – a field very hard to evaluate – we chose thickness, stiffness and colour change, and additionally we submitted the treated sheets to a subjective assessment of 15 observers.

Table 1: The papers

Paper	Origin	Fibre	ash (%)	pH [a] (surface)	g/m²	thickness (mm)
filter	produced by J.C.Binzer Papierfabrik, Hatzfeld, Germany, 1994.	100% chemical pulp	0,26	5,8	60	0,13
coated [c]	produced by Scheufelen Papierfabrik, Lenningen, Germany,1994	10% rag, 85% chem., 5% mech. pulp	28,2	7,4	127	0,13
groundwood 19th cent.	Bibliotheca Döllingeriana. München 1898	20% chem., 80% mechanical .pulp	11,9	4,4	70	0,07
groundwood 29th century	Kojinbetsu chinginchosa kekkahoku. Tokyo 1948	40% chem., 60% mechanical. pulp	11,9	3,1	49	0,08
rag 17th century [b]	Caspar Klock: Conciliorum tom.II. Nürnberg 1649	100% rag	1,15	6,7 (margin) 5,8 (print)	78	0,10 to 0,13
rag light [b]	Caspar Klock: Conciliorum tom.II. Nürnberg 1649	100% rag	1,15	5,5 to 6,5 (margin) 4,7 (print)	78	0,10 to 0.13

a. surface
b. The sheets of paper A are from the same book, but there is a difference regarding pH and yellowing. Two groups can be formed. Light: CIE L*= ca. 84 – a* = ca. 2,5 – b* = ca. 14. Dark: CIE L* = ca. 74 – a* = ca.5 – b* = ca. 17. The reason for this difference might be different sizing or different storage immediately after production. This difference is corresponding to the behaviour during accelerated ageing (see below).
c. coating: calcium carbonate and china clay; starch, styrene, butadiene.

THE PAPERS

As just stated, we had good reasons to do our research not only on new and well defined papers, but also on old ones, representing those which are really treated according to the conservation methods in question. Using old papers has some risks: there is only a limited amount which may not be enough for all desirable tests and which may run out when, in the course of progressing research, additional tests might become desirable. The paper of an old book, apparently throughout the same, may prove to be different in the course of progressing research, mainly during accelerated ageing, and this in qualities hardly to be manifested in terms of the usual paper analysis. Generally, old papers, and particularly those from the hand-making period, are much more different than modern ones, as well one sheet from the other as also the sheets within themselves. Nevertheless, it should be considered imperative to base research projects on conservation treatments on true old paper. Realistic results which can be used for choosing the method best apt for a certain damage and a certain old object can only be expected under this condition. The papers chosen for the project reported here are given in Table 1.

STRENGTHENING TREATMENT

The strengthening treatments to be examined for their effect were the following:

- Paper splitting. As this method is quite new[3 5 8 9 10 11], i.e. not fully experienced in all its possibilities and variants it has been executed using three different adhesives for the core (Japanese tissue, 0,05 mm [a])
  - Wheat starch paste
  - Methyl cellulose [b]
  - Acrylic emulsion
  - Leafcasting, i.e. an extremely thin paper in the leafcasting machine and couching it wet-in-wet forming onto the paper to be treated
- Laminating, i.e. sealing the commercial product “Filmoplast R™” [d], a Japanese tissue coated with an acrylic, onto the paper in question
- Parylene, i.e. coating the paper in question with a thin film of Parylene. This method is the only one among those checked here which can be defined to be a mass method as the books must not be unbound for treatment.

a. product no. 611140 as delivered by JAPICO Feinpapier GmbH, Frankfurt, Germany; 0,05 mm
b. type MH 300; product of Hoechst AG , Höchst, Germany
c. Plextol P565, poly acryl acid butyl ester, product of Röhm AG, Darmstadt, Germany
d. produced by Hans Neschen GmbH & Co. KG, Bückeburg, Germany

Leafcasting, splitting and lamination was done in the restoration institute of the Bavarian State Library in Munich, Germany (Institut für Buchrestaurierung: IBR); Parylene was applied by the company offering this method, i.e. by SCS Speciality Coating Systems, Inc., Nova Tran™ Parylene Coating Services, Clear Lake, 54005, USA. For leafcasting and paper splitting, the papers were previously washed, as it is usually done in conservation practice. For laminating with a heat-set tissue and for the Parylene process this pre-treatment is not necessary. On the contrary: laminating as described is preferably done when a wet treatment is not possible, because the object to be restored is highly water sensitive.

LEAFCASTING

As the method to strengthen paper in the leafcasting machine seems not yet to have been described enough in detail, at least not in the English language[12], to bring the conservation world to take notice of it as a commended method ousting traditional lamination using starch paste or MC and claiming to compete with paper splitting, possibly being superior to this modern method from the aesthetic viewpoint, such a description shall be given here.

Leafcasting for paper strengthening is done in the context of traditional leafcasting, i.e. to fill in missing parts. A special machine is necessary, and to do the process in a high aesthetic quality it should be a machine which allows an accurate work: zero or negligible loss of fibre, adjustable suction, adjustable working area. Moreover, for high quality leafcasting accurate computing is necessary: how much fibre is needed to produce a sheet of a certain thickness down to 0,01 mm of a certain colour to be mixed out of predied fibre. As third condition for results of high aesthetic quality, a certain relation between size of the aspired paper, its thickness and concentration of the fibre suspension shall be observed. All these requirements for optimum results, mainly based on experience and depending to some extent on the size of the machine, can only be met if the data are accurately computed, with the use of a PC[13], allowing reasonable time. For accurate computing specific data are necessary: numbers correlating to the mixture of pre-dyed fibre to gain a certain colour, i.e. exactly or as near as ever possible to that of the sheet to be treated, and numbers for the size of the missing parts. For both a machine should be available: for colour measurement, relevant instruments are well established in conservation research, a CIE L*ab instrument, e.g., and for measuring missing parts in a damaged sheet they can be specially constructed on the base using a light table, a camera, a monitor and again the PC[14].

The first step is traditional leafcasting to fill in missing parts. In the leafcasting program developed in the institute where this report originates there is the option for producing either a one-sided or a both-sided thin strengthening tissue out of the same fibre as used for filling-in, and it is also possible to put in the desired thickness: 0,01, 0,015, 0,02 mm etc., depending on the restorer’s opinion, with regard to the state of the object in question. The PC output gives numbers for how many sheets of the object in question can be treated in one process, how big the working area in the leafcasting machine should be with regard to the specific data (size, thickness, missing parts) of the object in question, or, in other words, what masks should be used to reduce the working area; moreover, the output gives numbers on how much fibre of different kinds must be suspended in a known volume of water and how much of this suspension must be used for filling-in the missing parts, for the first and for the second strengthening sheet. In the institute where the system described here has first been developed, i.e. in the Institute for Restoration of Books and Manuscripts in Munich, white cotton, chocolate-brown unbleached cotton linters and sulphate cellulose pre-died in several tints of reddish brown, yellow and blackish blue are used, so that every possible colour that is found in old paper can be imitated.

After leafcasting to fill in missing parts the screen with the sheets (Fig. 1) are put out of the machine, quickly pressed, and the sheets are brushed with thin starch paste or methyl cellulose. Then the first strengthening sheet is made, using the same suspension in the amount given by the computer and using the same masks as before (only inversely positioned, i.e. the mask used to limit the leafcasting area at the left side put now to the right), thus getting a strengthening sheet of

Fig. 1: The screen with leafcast sheets lying in the machine

exactly the size and the colour of the filling-in process and exactly of the aspired thickness. The strengthening sheet made as described is put without pressing, just in the condition as it comes out of the machine, i.e. not yet as a paper but as a thin mud of fibre, wet-in-wet and upside-down onto the leafcast sheet made previously (Fig. 2). Another quick pressing, turning the object upside-down, replacing the sieve used for filling-in by a synthetic non-woven (Hollytex™) and putting the second strengthening sheet, produced in the same way as the first, on the other side of the object in question. The whole process takes some minutes, the number of sheets treated simultaneously is depending on the working area of the leaf-casting machine. The newly produced paper at the margins of the sheets treated in this way can be removed when they are still wet; this will be done when the margins are not damaged and when it is desirable to keep their original shape, in the case of deckle edge paper, e.g.. Or they can be cut off after drying, leaving behind on the margin the overlapping fibre that is connecting the new paper to the old and that is drastically increasing the tear resistance of brittle paper. If – nearly invisibly – a small rim of new paper is left all around the old, this increase is even higher.

Fig. 2: Putting the second strengthening sheet onto the backside of the leafcast sheets lying on Hollytex

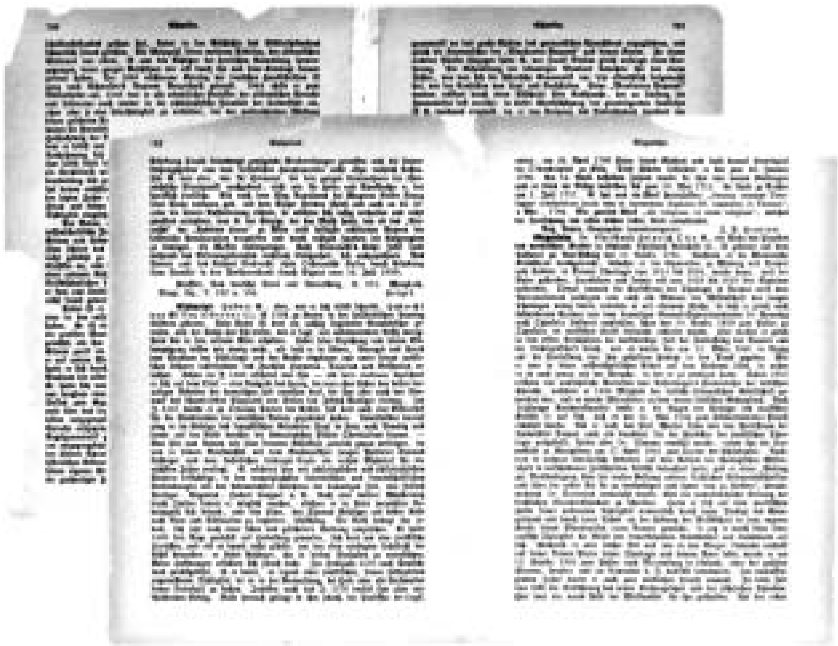


Fig. 3: Brittle paper, before and after strengthening in the leafcasting machine

ACCELERATED AGEING

From all papers treated in the manner as described (splitting, leafcasting, laminating with an acrylic, Parylene coating) one half was submitted to accelerated ageing at 90° 50% for 518 h. The reason for the deviation from accelerated ageing according to ISO 5630 were those of time: the higher the temperature the greater the changes in physical (and chemical) qualities of the material in proof. Altogether, the conditions of accelerated ageing are of minor importance, as relevant results can only be evaluated in comparison within one and the same research project. Accelerated ageing can give only an idea on the direction of the object's behaviour in real ageing, not of its degree. Relevant research must be rerestricted to one single different quality between the papers to be compared:

These papers must be the same with the exception of the very one quality in question[15]. Moreover, the different ageing methods are giving more or less parallel results, as can be seen when same papers are submitted to different ageing methods[16]. The results must be consistent. If they are not, as it is sometimes

Table 2: Tensile post fold N (average)

	control	washed	split paste	split MC	split Acrylic	leaf-cast	lami-nated	Pary-lene
filter MD								
unaged	9,70	9,35	60,98	63,91	24,71	32,78	41,22	34,77
aged	8,21	7,58	43,68	67,49	15,98	36,84	21,57	24,29
filter CD								
unaged	2,69	3,23	29,32	50,99	13,81	19,34	19,37	27,20
aged	3,08	2,38	25,67	56,42	11,13	18,95	13,50	23,26
coated MD								
unaged	64,10	69,15	114,28	128,05	59,24	68,87	89,32	62,90
aged	60,55	60,75	74,68	76,05	57,24	62,66	66,09	57,66
coated CD								
unaged	22,48	22,27	48,94	52,03	30,36	26,70	42,28	23,96
aged	20,36	21,73	40,00	52,99	28,24	27,67	26,32	22,46
groundwood 19th cent. MD								
unaged	14,00	11,73	37,82	52,26	28,97	22,28	40,38	23,13
aged	4,06	8,84	30,70	22,45	20,51	21,48	25,51	2,15
groundwood 19th cent. CD								
unaged	8,89	8,23	32,10	25,28	25,66	15,86	31,05	20,49
aged	2,24	4,31	28,73	20,77	18,15	15,66	20,79	1,45
groundwood 20th cent. MD								
unaged	14,06	21,80	23,29	19,21	21,92	30,55	37,55	10,64
aged	9,05	12,45	16,20	12,79	15,63	21,66	22,45	1,29
groundwood 20th cent. CD								
unaged	6,12	7,36	20,18	23,14	14,87	16,28	37,18	7,93
aged	2,05	3,36	12,07	12,02	11,83	14,65	20,45	0,48
rag 17th century MD								
unaged	10,45	11,36	40,93	53,46	28,67	17,60	43,25	49,95
aged	6,43	8,15	38,29	39,96	21,87	19,34	27,97	39,62
rag 17th century CD								
unaged	8,18	7,35	33,35	34,50	17,88	11,60	23,98	37,09
aged	3,99	4,84	24,67	34,50	16,19	14,68	15,93	25,21
rag 17th century light MD								
unaged	10,33	9,09	47,21	10,81	29,96	34,30	48,66	51,21
aged	18,24	13,08	23,46	56,38	38,30	29,05	32,71	35,31
rag 17th century light CD								
unaged	9,59	6,88	34,81	24,33	27,90	21,50	26,19	35,26
aged	7,59	3,59	27,49	28,76	32,10	23,78	18,08	26,22

Table 3: Relative change (%) of tensile post fold (sqrt(MD*CD) caused by treatment (upper part) or by treatment after ageing

	control	washed	split paste	split MC	split Acrylic	leafcast	lami-nated	Pary-lene
filter								
unaged	100	108	828	1118	362	493	553	602
after ageing	100	84	666	1227	265	525	339	473
coated								
unaged	100	103	197	215	112	113	162	102
after ageing	100	103	156	181	115	119	119	102
groundwood 19th century								
unaged	100	88	312	326	244	168	317	195
after ageing	100	205	985	716	640	608	764	58
groundwood 20th century								
unaged	100	137	234	227	195	240	403	99
after ageing	100	150	325	288	316	414	497	18
rag 17th century								
unaged	100	99	400	465	245	155	348	466
after ageing	100	124	607	733	371	333	417	624
rag 17th century, light								
unaged	100	79	407	163	290	273	359	427
after ageing	100	58	216	342	298	223	207	259
unaged = 100; after ageing:								
filter	98	77	79	108	72	105	60	77
coated	92	93	73	78	95	97	68	93
groundwood 19th c.	27	63	85	59	71	98	65	8
groundwood 20th c.	46	51	65	59	75	80	57	9
rag	55	69	83	86	83	118	66	73
rag light	118	87	63	248	121	97	68	72

the case[17], the ageing method must be examined and a specific reason for the deviation must be explained.

RESULTS

The data of measurements done at the altogether 80 samples (5 papers x 8 states of treatment (6 strengthening treatments plus washing plus control) x 2 states of ageing) or 96 samples (6 papers including “rag light”) are given in Table 2, 4 and

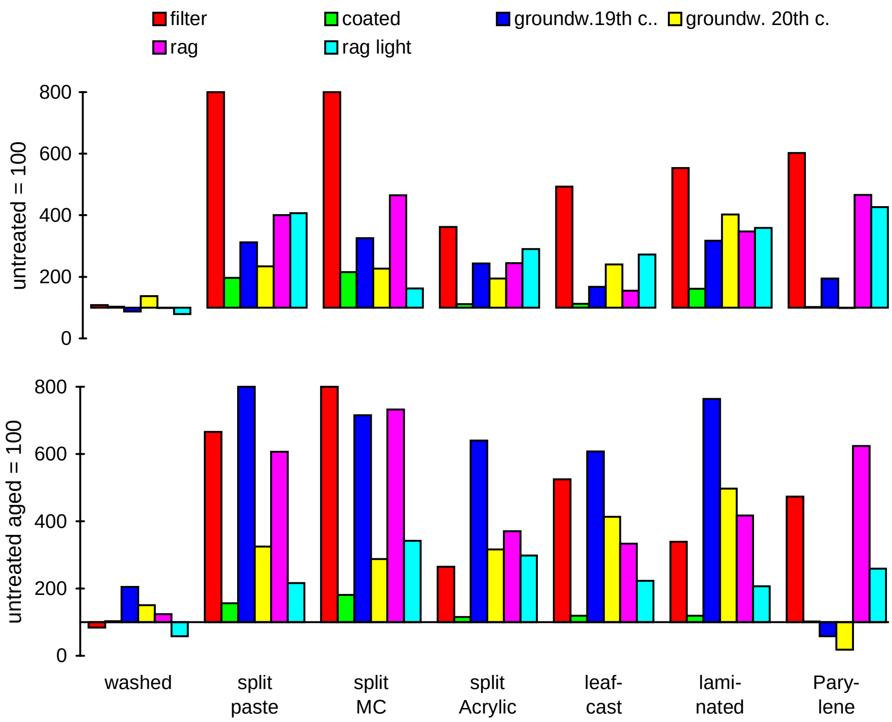


Fig. 4: Relative strengthening effect given as arithmetic middle: sqrt(MD*CD)

5. Table 3 is showing the relative change as percent of the untreated control, before and after ageing. Fig. 4–8 are showing, for clearer presentation, the numbers, either the measured ones or the computed relative changes, in form of diagrams.

EVALUATION OF RESULTS: STRENGTHENING EFFECT

As stated above, only one measurement was chosen to represent the term "strength" or "strengthening effect": tensile strength after one defined fold. From the upper part of Fig. 4 it becomes clear that not all treatments really have a significant strengthening effect on all papers. As none of the treated paper was so weak that it really needed to be strengthened, this issue is of no relevance. Rather, in this actual state, it demonstrates a strong valid principle in any conservation treatment. A good conservation procedure should change as little as possible the original features, while at the same time effectively arrest deterioration of the object being treated. The coated paper, e.g., which is "very strong" (class I) [7] and

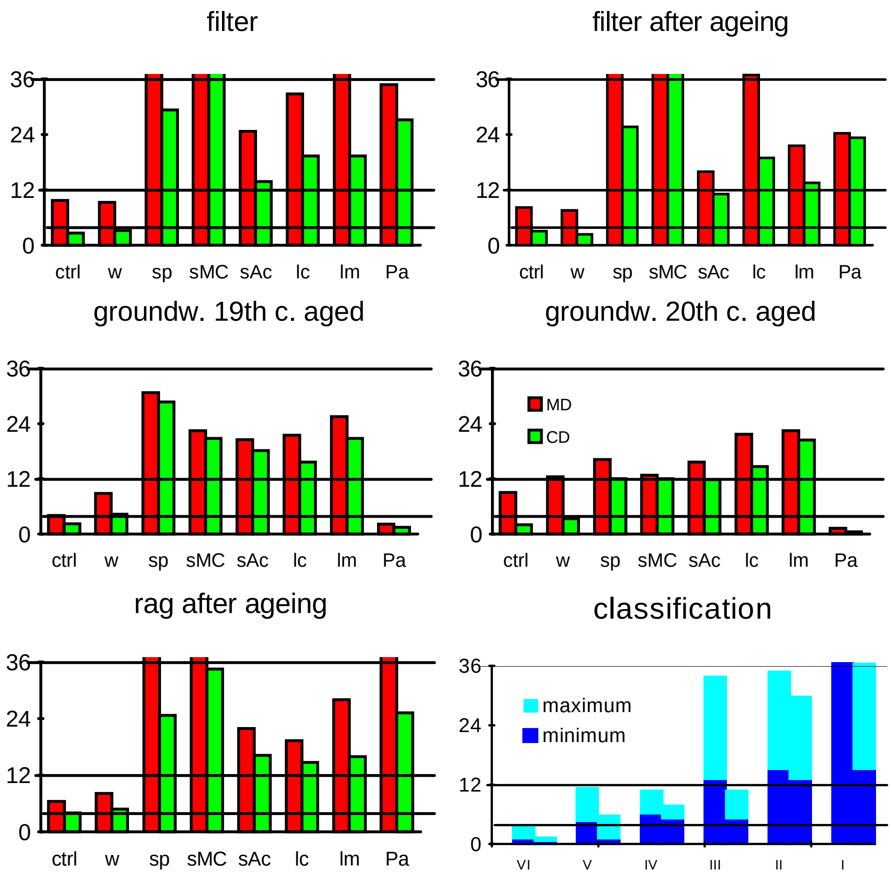


Fig. 5: Increase of Tensile post fold in terms of usability classification[7]

does not need to be strengthened, became even stronger up to the double by splitting using paste or MC as adhesive for the core. By overall strengthening in the leafcasting machine and by coating with Parylene, however, the strength was increased only by a small percentage: nearter to the original. Of some importance may be that the strength of one of the groundwood papers (20th cent.), indeed “usable without restriction” (class III)[7] but fulfilling just the minimal requirements of this class, is nearly not touched by the Parylene treatment. By all other treatments the strength of this paper is at least doubled or nearly doubled (splitting using an acrylic: 195%). The strength of the filter paper, which, due to its production without sizing and its intended use for technical purposes, would be "to be used with care" (class V)[7] if it were used for printing, is improved at least more than three times by any treatment.

More important is the effect on the papers after ageing. Three papers, namely groundwood 19th, groundwood 20th and rag, are declassified by accelerated ageing from class III[7] "usable without restriction", to class V: "to be used with care". From Fig. 5 it can be seen that any treatment with the exception of Parylene has brought them to class II: "strong".

Fig. 6 is demonstrating that the ageing behaviour of the old papers – with the exception of groundwood coated with Parylene – is significantly improved. On the ageing behaviour of the new papers – filter and coated – the splitting methods and lamination seem to have a slightly negative influence, but the elevant data must not be overestimated. The absolute strength values of the two split papers after ageing are by far higher than that of the untreated control. Very striking, however, is the effect of Parylene coating on the groundwood papers after ageing. Both such papers are in a much worse condition than the control samples. Possibly this has to do with the observation done recently that paper aged in a staple is suffering significantly greater decay than when aged as single sheets[18 19]. The Parylene coating might produce an airtight closure and retain volatile degradation products which provoke further decay, what may also be the reason for the enhanced decay rate in the inner of a staple. The other strengthening treatments seem not to retain these volatile degradation products. Obviously, they can evaporate from the upper layers of the split samples and through the thin strengthening tissue produced in the leafcasting machine; more conspicuous is that this seems to be the case also with the thin acrylic foil or layer of hotmelt used for lamination.

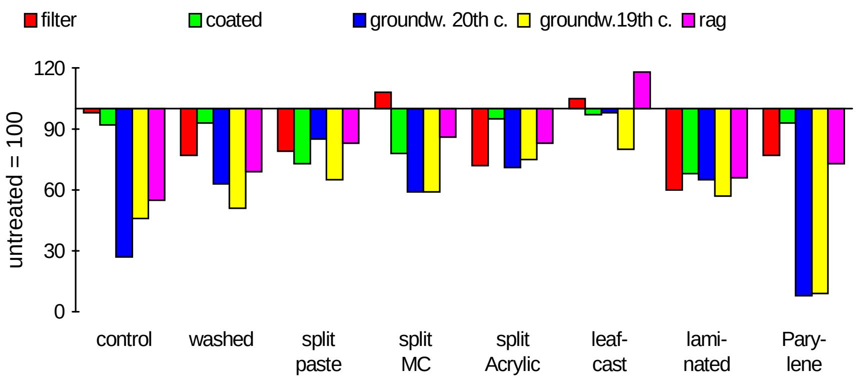


Fig. 6: Relative change of strength caused by ageing

Table 4: Thickness and stiffness

Thickness(µm)	control	washed	split paste	split MC	split Acrylic	leafcast	lami-nated	Pary-lene
filter	136	156	147	116	209	114	178	151
coated	101	110	145	126	234	135	168	104
groundwood 19th century	71	74	128	108	130	95	145	79
groundwood 20th century	72	75	117	92	128	81	130	74
rag	132	129	145	136	256	118	163	134
Stiffness (N)								
filter	0,14	0,15	0,15	0,12	0,22	0,11	0,20	0,16
coated	1,40	1,43	3,05	2,48	4,32	1,54	2,46	1,47
groundwood 19th century	0,13	0,21	0,67	0,72	0,41	0,20	0,54	0,47
groundwood 20th century	0,20	0,18	0,70	0,30	0,31	0,18	1,23	0,25
rag	0,19	0,12	0,62	0,93	0,43	0,31	0,90	0,23

AESTHETICS

As it is very difficult to describe such a delicate matter as “aesthetic quality” of a restoration treatment in terms to be comprehended generally, three qualities have been chosen that, on the one hand, can be measured, and, on the other, are of impact on aesthetics. These qualities are: Thickness (Table 4, Fig. 7 upper part), Stiffness[20] (Table 4, Fig. 7 lower part) and Colour change according to the CIE L*ab system (Table 5, Fig. 8). Additionally fifteen different persons, five restorers, five librarians acquainted with old, rare and valuable books and five persons from outside the world of books and the world of conservation, have been asked to give a ranking what of the six samples, differentiated by the treatment, in each of the five groups of paper they think to have suffered the slightest, second slightest change, or, in other words, are, in their aesthetic appearance, nearest, second nearest etc. to the untreated control. The librarians and even more the outsiders, who were not familiar with restoration treatments, gave their ranking impartially. The restorers, of course, understood, more or less, what strengthening method was used, so that personal preferences could influence their ranking. There was, however, no significant difference between the rankings done by the three groups. Generally, the correlation in terms of mathematics[21] is low: Kendall coefficient between 0,5 and 0,77. The results of this subjective assessment are given in Fig. 9.

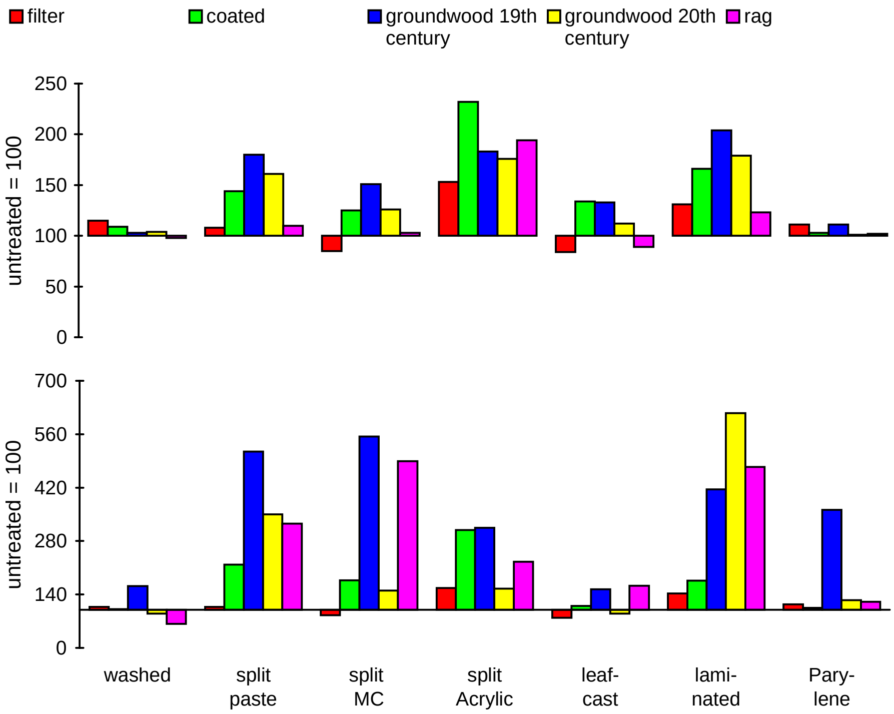


Fig. 7: Relative change of thickness (upper part) and stiffness (lower part)

Thickness and Stiffness

The generally smallest change in thickness is resulted from Parylene coating and overall strengthening in the leafcasting machine. Parylene almost does nearly not affect thickness. Papers which are somewhat fleecy, as filter and old rag, become a little bit thinner by the pressing that is an unavoidable part of the leafcasting process. With the others the thin tissue on the surface is hardly measurable; it seems to be pressed into the surface even of the smooth papers, i.e. the coated one and the 20th century groundwood.

All splitting processes provoke an increased thickness, less if paste or MC is used as adhesive for the core, more with the acrylic. The lower compatibility of synthetics with paper can also be seen from the increased thickness of the laminated papers.

Table 5: Colour change: CIE L*ab

		control	washed	split paste	split MC	split Acrylic	leaf cast	lami-nated	Pary-lene
filter									
L*:	unaged	94,3	93,2	91,9	88,9	94,6	93,7	94,2	94,1
brightness	aged	89,1	87,6	86,9	77,7	88,4	88,1	85,4	88,8
a*	unaged	0,0	0,1	0,3	-0,1	0,0	0,1	0,1	0,2
green-red	aged	1,8	2,1	2,3	3,5	2,1	2,0	2,5	1,8
b*:	unaged	5,2	6,3	6,8	7,0	6,2	5,9	6,9	6,1
blue-yellow	aged	11,5	16,5	18,9	20,0	11,7	13,2	16,6	10,7
coated									
L*:	unaged	94,9	94,0	93,9	93,9	96,1	95,3	94,8	96,0
brightness	aged	92,4	92,4	91,4	91,0	93,8	92,5	86,0	93,2
a*	unaged	0,9	0,6	0,6	0,7	1,6	0,8	1,3	1,6
green-red	aged	0,4	0,4	0,6	0,7	0,5	0,4	1,8	0,0
b*:	unaged	-2,3	-0,3	0,8	0,2	-4,9	-0,9	-3,7	-4,9
blue-yellow	aged	10,3	10,2	10,8	12,1	6,4	9,1	23,3	6,4
groundwood 19th century									
L*:	unaged	85,7	85,6	84,7	82,9	82,59	84,7	85,3	82,1
brightness	aged	79,6	80,8	80,5	78,8	75,21	80	75,2	70,9
a*	unaged	2,3	2,32	2,19	2,71	3,02	2,3	2,57	4,35
green-red	aged	5,51	4,66	4,64	5,24	7,54	4,66	6,97	9
b*:	unaged	19,4	18,7	21,7	22,5	20,79	20,4	19,1	23,8
blue-yellow	aged	22,9	22,9	26	26,1	28,87	23,7	28,5	26,8
groundwood 20th century									
L*:	unaged	79,5	78,5	75,2	73,4	72	75	79,2	79,6
brightness	aged	75,4	72,7	72,6	72,3	68,38	73,4	69,9	66,2
a*	unaged	5,63	3,68	3,61	4,15	5,13	4,04	4,3	4,98
green-red	aged	7,63	5,86	5,62	6,29	7,64	6,75	7,71	9,18
b*:	unaged	23,1	18,7	20,7	21,8	22,93	21,1	19,4	21,3
blue-yellow	aged	25,5	22,9	24,6	25,4	26,25	26,3	25,9	24
rag light									
L*:	unaged	78,9	82,9	77,9	83,9	84,1	81,6	83,3	80,0
brightness	aged	78,7	76,9	72,2	71,9	76,5	74,2	76,9	69,0
a*	unaged	2,9	2,3	2,2	2,0	2,5	2,9	2,4	3,1
green-red	aged	3,5	3,9	5,1	4,1	3,9	3,4	3,7	5,3
b*:	unaged	12,8	14,8	12,6	13,1	14,2	15,1	14,2	15,5
blue-yellow	aged	15,9	17,6	20,5	19,5	16,5	15,5	16,8	18,0
rag dark									
L*:	unaged	73,1	73,7	76,2	79,7	74,2	80,6	82,3	74,5
brightness	aged	57,0	71,2	65,6	64,2	67,5	55,9	62,2	
a*	unaged	3,0	4,0	4,3	3,1	4,7	4,0	2,3	4,7
green-red	aged	5,0	5,3	5,9	5,6	4,8	3,9	4,6	
b*:	unaged	13,7	15,6	17,8	14,9	16,7	17,6	12,5	18,6
blue-yellow	aged	13,9	19,4	19,2	19,4	16,0	11,1	14,0	

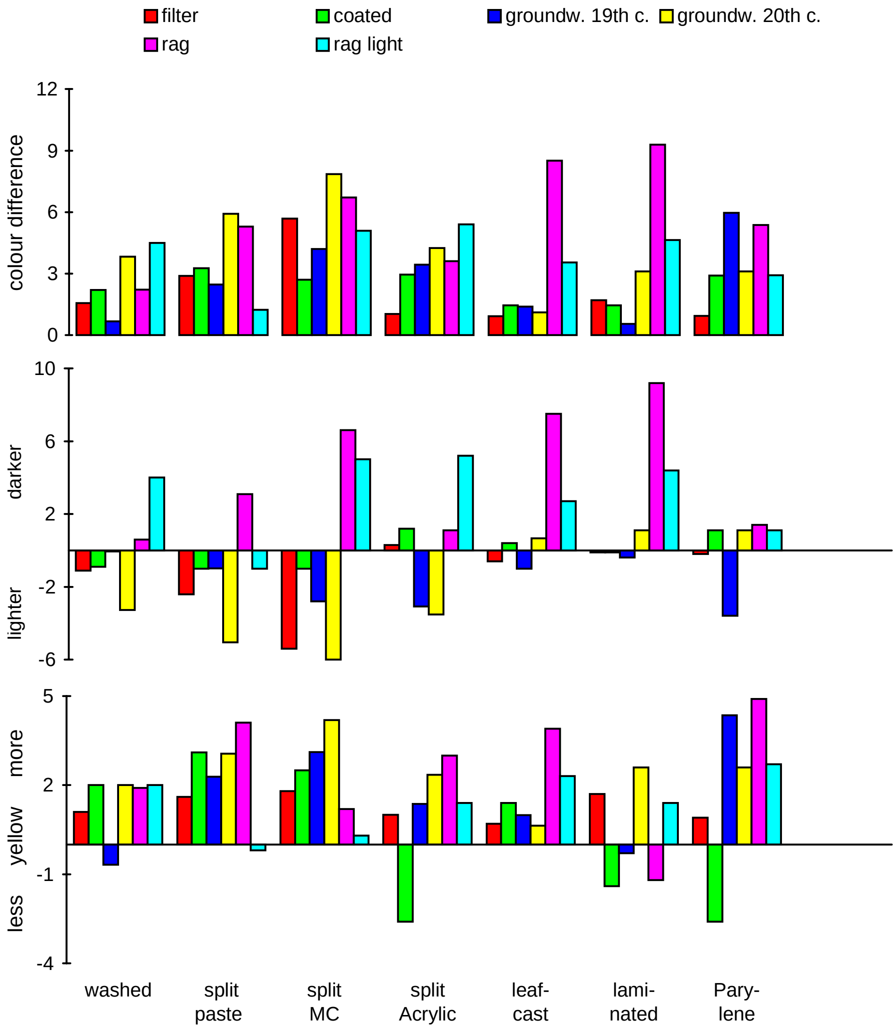
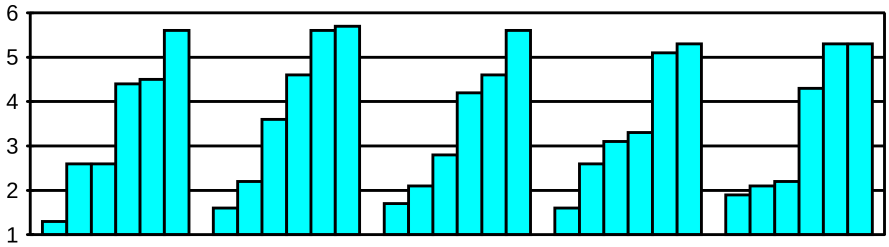


Fig. 8: Colour change

Regarding the change of stiffness, there is a clear superiority of the leafcasting process; likewise the Parylene treatment is resulting in nearly no increased stiffness. The exception (groundwood 20th century) may again be the result of uneven application. The papers have been Parylene treated as book blocks slightly fanned, as it is the normal condition of this treatment. This method results in half-



filter	coated	gr.19th c.	gr.20th c.	rag
leafcast	Parylene	leafcast	Parylene	leafcast
split paste	laminated	Parylene	leafcast	Parylene
Parylene	split MC	split paste	split MC	split paste
laminated	split paste	split MC	split paste	split MC
split MC	split Acrylic	split Acrylic	split Acrylic	laminated
split Acrylic	leafcast	laminated	laminated	split Acrylic

Fig. 9: Personal assessment

moon-shaped parts where less coating is achieved, down to none, while the outside parts of a sheet get a more intensive coating.

Splitting and lamination methods result in an increase in thickness up to more than five times. The measured numbers are in a wide range: obviously the result of unevenly applied adhesive

Colour Change

Any treatment changed the colour of the samples, and it is difficult to see a regularity. Possibly the old rag paper must be excluded from observation, because it is too irregular in itself. A colour measurement may only give reasonable results if exactly the same spot is examned before and after a treatment instead of different samples of the same kind, as it was done for this project.

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Restricted to the more uniform, i.e. the machine made papers, overall strengthening in the leafcasting machine has obviously effected the smallest colour change: the samples have become a little bit more yellow. Any splitting method had the same result, but in a remarkably higher degree. Splitting, mostly if done with starch or MC as adhesive for the core, slightly increases the brightness of the paper, as explained by the removal of coloured products of paper decay in the enzyme bath which is used to remove the support paper. Note that: the colour of these decay products which constitute yellowing is not yellow in the chronometric meaning; it is "dark". The "yellow" tint of the papers has been slightly increased by the splitting process. All these colour changes are beyond visibility.

Subjective Assessment

As just mentioned, the ranking done by fifteen persons consulted for their opinion which of the six treatments have changed the five papers the least, more and the most, is far from being uniform. Regarding filter paper, the older, and in the context of aesthetics more important, the more fleecy groundwood and historic rag, leafcasting is nearest to the principle that conservation treatment should not change the aesthetic appearance of an object. For smooth papers, i.e. for coated and calandered ones, as is the newer groundwood, Parylene is the winner. Possibly Parylene is the method of the future for coated papers, when graphs of artistic value and therefore, if damaged, to be restored in the original format, will come into the restoration workshop.

CONCLUSION

As a general result it can be stated, that splitting, overall strengthening in the leafcasting machine and laminating give good strength to paper endangered by brittleness and have a good ageing stability. From the aesthetic point of view leafcasting turns out to be superior to the other methods. If really brittle papers are concerned, as they participated in this project only in their state after ageing, this statement might need to be limited: Overall strengthening by leafcasting means that the strengthening fibre is put onto the surface of the object, while for splitting it is put into the interior. Possibly for brittle paper the tissue must be made thicker: so thick that the aesthetic appearance is affected. For splitting of re ally brittle paper a thicker core might be necessary, again with negative influence on aesthetics, i.e. on thickness and stiffness. Any synthetic adhesive, it might be used for the core in splitting or as hotmelt for laminating was found to have a negative influence on the papers as compared to starch and methyl cellulose. Parylene, on the other hand, again a synthetic, gave surprisingly positive results: very satisfactory for modern smooth papers, best apt for the coated. Highly alarming, however, is the negative influence of this treatment on the ageing behaviour of groundwood paper. Its mechanism and the relevance of the results of accelerated ageing to the real ageing behaviour must be further studied.

Summaries

The Effect of Different Strengthening Methods on Different Kinds of Paper

Five different papers, three old ones, as they might be the object of a strengthening treatment in the restoration workshop, have been strengthened according to four different relevant treatments (or six, as one of them was used in three variants), submitted to accelerated ageing and checked for the strengthening effect, its stability and for change in aesthetic appearance. All methods, namely splitting using different adhesives for the core, overall strengthening in the leafcasting machine, lamination using a heatset acrylic and Parylene coating, gave sufficient strength to the papers, Parylene coating with the alarming exception that it provokes enhanced decay during accelerated ageing of groundwood paper. The impact of the different strengthening methods is depending on the kind of paper. Leafcasting seems to be best apt for old, Parylene coating for modern supercalandered and coated paper. As one of the methods, i.e. overall strengthening in the leafcasting machine is not very well known in the conservation community, a more detailed description is given to explain the procedure.

L'effet des différentes méthodes de consolidation des différentes sortes de papier

Cinq différentes sortes de papier, dont trois anciennes, dans l'état où elles se trouvaient lorsqu'elles sont arrivées dans l'atelier de restauration afin d'y être consolidées, ont été traitées selon quatre méthodes différentes (ou selon six, car une des méthodes a été appliquée en trois variantes), puis soumises à un vieillissement accéléré et testées sur l'effet de consolidation obtenu ainsi que sur leur résistance au vieillissement et sur le changement de leur apparence esthétique. Toutes les méthodes, c'est-à-dire l'exfoliation du papier en utilisant différentes colles pour le noyau, le renforcement de la surface avec une couche de fibre à l'aide d'une machine, le laminage avec une résine acrylique et l'enduction de parylène, donnent une solidité suffisante aux papiers avec l'exception alarmante que le parylène provoque lors du vieillissement accéléré une dégradation nettement plus rapide du papier de pâte mécanique. L'influence des différentes méthodes de consolidation sur l'apparence esthétique du papier varie selon les différentes sortes de papier. Le renforcement mécanique de la surface avec une couche de fibre semble être la méthode la mieux adaptée pour les papiers anciens alors que le procédé au parylène convient aux papiers modernes hypercalandrés et aux papiers couchés. La méthode du renforcement de la surface en utilisant un laminoir n'est pas très connue dans le monde de la restauration, on donnera une description plus détaillée pour expliquer la procédure.

Die Wirkung verschiedener Festigungsmethoden auf verschiedene Papierarten

Fünf verschiedene Papierarten, davon drei alte, wie sie zur Festigung in die Restaurierwerkstatt kommen mögen, wurden nach vier verschiedenen Methoden entsprechend behandelt (oder nach sechs, da eine in drei Varianten angewandt wurde), dann beschleunigt gealtert und auf die erzielte Festigungswirkung, deren Alterungsbeständigkeit und auf die Veränderung des ästhetischen Erscheinungsbildes untersucht. Alle Methoden, d.h. Papierspalten unter Verwendung verschiedener Klebstoffe für den Kern, Übervliesen im Anfasergerät, Laminieren mit einem Acrylat-Schmelzkleber und Beschichten mit Parylene geben hinreichend Festigkeit, Parylene freilich mit der alarmierenden Ausnahme, daß es beim beschleunigten Altern den Abbau von Holzschliffpapier deutlich befördert. Der Einfluß der verschiedenen Festigungsmethoden auf das ästhetische Erscheinungsbild unterscheidet sich nach den Papierarten. Für alte Papiere erscheint Anfasern als am besten geeignet, für moderne kalandrierte und gestrichene das Parylene-Verfahren.

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