The Deterioration of Book Paper in Library Use

By HARRY F. LEWIS *

Institute of Paper Chemistry

THE following report describes an experiment begun in 1934 by a joint committee of the American Council of Learned Societies and the Social Science Research Council — the Joint Committee on Materials for Research. The experiment was set up in the hope of answering two questions. First, will a book printed on paper made from highly purified woodpulp, known as Solka pulp, hold up as well under library use as a book printed on the the same weight paper made of 100% rag stock? Second, to what extent do such variables as geographic location, degree of use, and atmospheric conditions affect the degree of deterioration in books printed on both rag and purified woodpulp sheets?

In order to answer these questions the Joint Committee on Materials for Research proceeded as follows. The American Council of Learned Societies had in process of publication the 20-volume *Dictionary of American Biography*, the first volume of which appeared in 1928 and the twentieth in 1937. Charles Scribner & Sons of New York were the printers and publishers. Arrangements were made in 1934 with Scribner to print 25 extra test copies of volume 13, at that time ready for the press. These test copies differed from the ordinary trade copies in that sections of each were to be printed on three different kinds of paper — two kinds of 100% rag paper and one of 100% Solka pulp.

Test data on the sheets were given in an insert in the test copies entitled "Memorandum About the Paper Stock of this Volume." It must be assumed that the chemical and physical testing procedures reflected in the figures supplied were those in common use in 1934. To what degree the test data reported were truly representative of the experimental lots of paper cannot now be determined. I tried to check them by getting the original notes of the respective company laboratories; but, of the three paper companies involved, only the first — the American Writing Paper Co. — is still operating. The Worthy Paper Co. Assn. no longer exists, and its records could not

* Dr. Lewis is the vice president of the Institute of Paper Chemistry, Appleton, Wisconsin.

be found. Nor could pertinent records be found of the Dill & Collins Paper Co., which had been bought by the Mead Corp. I am indebted to Helen Kiely, former director of research for the American Writing Paper Co., for supplying detailed information from the original records of that company.

The 25 test copies, together with the regular copies of volumes 13, were sent out to a carefully selected list of libraries variously located in city and country, at sea level and higher elevations and in cold, warm, and temperate climates. Each library was asked to put the test copy on its shelves with the set and to store the trade copy until the experimental copy was called in for testing, when the trade copy would replace it. To what degree this procedure was followed is not known. Personnel changes with time, and original agreements may be forgotten. The institutions that received the 25 test copies were the following:

TABLE I

Copy No.	Location
1.	Dartmouth College, Hanover, N. H.
2.	Boston Public Library, Boston, Mass.
3.	Columbia University, New York City.
4.	New York Public Library, New York City.
5.	New York Public Library, New York City.
6.	St. Lawrence University, Canton, N. Y.
7.	Library of Congress, Washington, D. C.
8.	University of North Carolina, Chapel Hill, N. C.
9.	Public Library, Jacksonville, Fla.
10.	Howard Memorial Library, New Orleans, La.
11.	St. Louis Public Library, St. Louis, Mo.
12.	Cincinnati Public Library, Cincinnati, Ohio.
13.	Cleveland Public Library, Cleveland, Ohio.*
14.	Carnegie Library, Pittsburgh, Pa.
15.	John Crerar Library, Chicago, Ill.*
16.	Iowa State College Library, Ames, Iowa.
17.	Butte Public Library, Butte, Mont.
18.	Colorado College Library, Colorado Springs, Colo.
19.	University of Arizona Library, Tucson, Ariz.**
20.	University of Southern California Library, Los Angeles, Calif.
21.	University of California Library, Berkeley, Calif.*
22.	Seattle Public Library, Seattle, Wash.
23.	Toronto Public Library, Toronto, Canada.*
24.	McGill University Library, Montreal, Canada.
25.	Dalhousie University Library, Halifax, Canada.

* Copy not returned.

** Copy lost either in transit or during storage awaiting test.

The first section of each test copy was printed on the same stock as that of the regular trade edition, namely "American Writing Paper," 100% rag, a stock weighing 60 lbs. to 500 sheets (25″ x 38″), made by the American Writing Paper Co. of Holyoke, Mass. This paper is here identified as sample *A*. The second section was printed on Worthy Permanent Book, 100% rag, white, a stock weighing 70 lbs. to 500 sheets (25″ x 38″), made by the Worthy Paper Co. Assn. of West Springfield, Mass. This paper is identified as sample *B*. The third section was printed on "Special Alpha Natural 60 lb. run d-27139, 100% Solka," a paper weighing 60 lbs. to 500 sheets (25″ x 38″), made by the Dill & Collins Paper Co., Philadelphia, from purified cellulose made by the Brown Co., Portland, Maine. This paper is identified as sample *C*. The information here given about the samples is taken from the memorandum in the front of each test book.

A description of the three papers is reproduced from the memorandum as Table II. The sample identification letters, *A*, *B*, and *C*, have been assigned only for reporting purposes.

TABLE II

MEMORANDUM ABOUT THE PAPER STOCK OF THIS VOLUME

This copy of Volume XIII of the Dictionary of American Biography is one of twenty-five run off as a test to determine how various kinds of paper stand up under actual working conditions.

Front matter and pages 1-198 are printed on the same stock as used for the regular trade edition, namely "American Writing Paper," 100% rag, a stock weighing on the basis of a 25″ x 38″ sheet, 60 lbs. to 500 sheets, made by the American Writing Paper Company, Holyoke, Massachusetts. The chemical tests of this paper give the following results:

[Sample *A*]

Alpha content — before aging	95.	%
— after aging	91.8	%
Copper number — before aging	.32	%
— after aging	.73	%
Rosin content	.97	%
Total acidity	.018	%
pH	6.4	%

Fold — before aging	*M	74.7
	** $\overline{C}$	48.5
— after aging	M	49.0
	$\overline{C}$	39.5

* M — Strips cut with the machine.
** C — Strips cut against the machine.

TABLE II (continued)

Pages 199-358 are printed on "Worthy Permanent Book, 100% rag, white," a stock weighing on the basis of a 25" x 38" sheet, 70 lbs. to 500 sheets, made by the Worthy Paper Company Association of West Springfield, Massachusetts. The chemical tests of this paper show the following results:

[Sample *B*]

Alpha content — before aging	95.41 %
— after aging	94.2 %
Copper number	.456 %
Copper number, increase in oven	.0201%
pH	6.3 %
Rosin content	.596 %
Folding endurance — not specified; loss in oven	5.8 %

Pages 359 to the end of volume are printed on "Special Alpha Natural 60 lb. run d-27139, 100% Solka," purified cellulose made by the Brown Company, Portland, Maine, a paper weighing on the basis of a 35" x 38" sheet, 60 lbs. to 500 sheets, and made by Dill & Collins Paper Company, Philadelphia, Pennsylvania. Chemical tests of this paper show the following results:

[Sample *C*]

Alpha content — before aging	90.7 %
— after aging	87.25%
Copper number — before aging	.92%
— after aging	.98%
pH	5.7 %
Rosin content	.2 %
Folding — before aging	5.5 %
— after aging	4.7 %
Loss in folding after aging	.8 or 14.5 %

In addition to the sheets specified above, two sample sheets of each stock are bound at the end of the volume to permit later checking or testing without harming the text.

The After-Use Test Program and Its Implications

In April 1955 — 21 years after the test volumes had been sent to the libraries — the Institute of Paper Chemistry was asked by the last surviving member of the Joint Committee, H. M. Lydenberg, former director of the New York Public Library, to test the quality of the paper in those experimental volumes and prepare a final report that could be submitted to the cooperating councils in completion of the experiment begun by the Joint Committee. The Institute agreed to carry out the desired chemical and physical tests and to prepare a report for submission. This is that report.

On July 15, 1955, a letter was sent out by Mr. Lydenberg to the cooperating libraries asking that the test volumes be sent to the Institute of Paper Chemistry. Eighteen of the original 25 test volumes were returned and tested. One of the test volumes was lost in shipment to the Institute of Paper Chemistry or was misplaced after its arrival.

The staff of the institute, after reviewing the original and final data, at first decided against publishing a scientific report covering the full study for a number of reasons relating largely to the physical tests on the paper. One reason was that the paper made with Solka pulp was a weak sheet if we accept the physical data provided for sample *C* in the memorandum reproduced above; nor is there any description of the folding test used to determine the actual fold value of this sheet. We know today that highly purified pulps are hard to convert on a 100% basis into book papers of acceptable physical properties; and today's mills would probably not attempt to do so even experimentally. Another reason against publication was that no reproducible physical data were supplied for sample *B*, made by the Worthy Paper Co. Assn. Although other questions could be raised regarding the scientific validity of comparing the original and the current data, the two reasons given seemed at the time to justify presenting only a generalized report to the cooperating societies and publishing nothing. After further consideration, however, we have decided to publish a somewhat modified report, calling attention both to weak points of the experiment and to results of significant interest.

The first question to which the experiment was meant to provide an answer was "Will a book printed on paper made with 100% Solka pulp hold up as well under library use as the same weight sheet made of 100% rag stock?" The second question was "To what extent do such variables as geographic location, degree of use, and atmospheric conditions affect the degree of deterioration in books printed on rag and Solka paper?"

1. Chemical tests made on the rag paper of the American Writing Paper Co. and on the purified woodpulp paper of the Dill and Collins Paper Co. show that neither sample had deteriorated to an unusual degree in any of the 18 locations. The test results on the second rag sheet (sample *B*) do not appear to be worth much consideration, but they are included in the appendix to this report.

The alpha-cellulose value of the rag sheet (sample *A*) was found in the test to range from 90.0% for the New York Public Library volume through 91.1% for the Pittsburgh volume, up to 94.7% for the Seattle volume. The alpha-cellulose value found in the

sample *C* paper ranged from 85.0% for the New York Public Library volume through 85.4% for the Pittsburgh volume up to 90.1% for the volume from Seattle. Part of this range may be due to a variation in the original alpha-cellulose values of the paper going into the different volumes. These should all have been tested before the volumes were sent out.

We have reason to believe that the original chemical tests of the rag paper (sample *A*) and the tests of it after the aging period were made by the same methods and that the results are therefore accurate within the limits of an empirical test. The chemical changes in this paper during natural aging may be summarized by saying that after 21 years rag paper *A* had lost on the average 2.6% of its original alpha-cellulose (resistant cellulose) and 1.3 pH units (indicating some increase in acidity), and had gained 0.8 units in copper number. The maximum loss in alpha-cellulose was 5.0% for the New York Public Library volume, and the minimum loss was 0.3% for the Seattle volume. These changes are all indices of chemical deterioration. The comparable indices of deterioration for the woodpulp paper (sample *C*) were not significantly different: alpha-cellulose loss, 3.7%; loss of pH units, 1.4; increase in copper number, 0.7 units. The alpha-cellulose values of both samples after 21 years of natural aging would still be regarded as excellent. From this fact it may be concluded that, given an original folding strength about equal to that of the rag stocks, the Solka sheet might have shown quite satisfactory aging results within the limits of the test.

An average of all the fold data for each sample in the two directions reveals that the folding endurance of sample *A* (American Writing Paper, 100% rag) was 62 and now is 10. The folding endurance of sample *B* (Worthy Permanent Book, 100% rag), for which no original value was given, now is 9. The folding endurance of sample *C* (Solka sheet) was 6 and now is 3. It should be noted that the folding endurance of the American Writing Paper is better now than the *original* folding endurance of the Solka sheet (of questionable value in view of our ignorance of the original test method).

Inasmuch as the original tensile strength values were not given, there is no way of telling how much the samples have deteriorated with regard to this property over the past 22 years.

There follows a summary of the averages for sheets from 18 copies of the volumes tested with high and low values and average change (Table III), and the complete chemical test data for each of the 18 copies (Table IV).

TABLE III

CHEMICAL TESTS ON RAG SHEET *A* AND SOLKA SHEET *C*

	% Alpha-Cellulose		pH		Copper Number	
	A*	C**	A	C	A	C
1. Original sample	95.0	90.7	6.4	5.7	0.3	0.9
2. Average (after use)	92.4	87.0	5.1	4.3	1.1	1.6
3. High	94.7 (22)	90.1 (22)	5.8 (22)	4.5 (22)	2.0 (4)	2.3 (14)
4. Low	90.0 (4)	85.0 (4)	4.2 (14)	4.0 (14)	0.72 (24)	0.89 (22)
5. Average change (1-2)	−2.6	−3.7	−1.3	−1.4	+0.8	+0.7

* American Writing Paper rag sheet.
** Dill & Collins Solka sheet.

The numbers in parentheses refer to the test copy numbers (Table I).

2. A quick review of the values for sample *A* and sample *C*, in Tables IV and V, shows that the greatest changes, both physical and chemical, had occurred in the books from Columbia University, the New York Public Library, the Carnegie Library of Pittsburgh, and the University of North Carolina. The least changes had occurred in the books kept in the Seattle and Butte public libraries, at Colorado College, and at McGill University. It is not easy to pinpoint cause and effect, but the books showing the greatest degradation were the ones that had apparently been most used; and those showing the least degradation were those in the best general condition, which had been subjected to least use. The Columbia and New York Public Library volumes had received hard enough use to require rebinding. Those from the Library of Congress, the Cincinnati Library, the Carnegie Library, and the University of North Carolina were described as being in "poor condition." Those from Colorado College, McGill, and Dalhousie were in such good condition as to suggest that they had been used very little. The cover of the Seattle volume, though it showed more wear than the three volumes just mentioned, was still in excellent condition.

Table VI provides a comparison of the tests for the New York Public Library volume, representative of the volumes in bad general condition; for the New Orleans volume, in fair to poor general condition; for the Iowa State College volume, in fair to good general condition; and for the Seattle volume, in good general condition. The ratings of condition were based on general appearance; the tests were for papers *A* and *C*. In this table the Seattle copy shows in general the least degradation by both physical and chemical tests. The New Orleans copy and the Iowa State copy show relatively slight differences but on all counts are below the Seattle copy. The New York copy shows the greatest degradation by a fairly wide margin.

TABLE IV

COMPOSITION OF PAPER SAMPLES AFTER USE

	Alpha Cellulose			Starch		Ash			Rosin			Viscosity			Hot Water pH			Cu. No.		
	A	B	C	A	B	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
1. Dartmouth College	91.7	90.7	88.1	2.4	0.7	8.0	7.5	8.9	.75	.70	.50	9.1	7.4	9.7	5.1	5.9	4.4	1.0	0.8	1.6
2. Boston Public *																				
3. Columbia University	92.8	89.1	87.7	2.4	0.5	8.6	7.0	8.9	.89	.65	.53	5.6	5.9	6.4	4.7	5.2	4.2	1.7	1.5	2.1
4. N. Y. Public	90.0	90.7	85.0	2.4	0.4	8.6	7.8	8.8	.97	.82	.59	5.1	5.2	6.8	4.2	4.8	4.1	2.0	2.0	1.9
5. N. Y. Public *																				
6. St. Lawrence U.	91.8	90.1	86.6	3.1	0.9	8.4	7.2	8.6	.69	.60	.46	8.9	7.8	8.7	5.1	5.9	4.4	.88	.74	1.4
7. Library of Congress	91.8	89.5	86.8	3.0	0.8	8.6	7.6	8.8	.77	.71	.49	6.6	6.0	6.8	4.9	5.5	4.2	1.5	1.4	1.8
8. U. of North Carolina	92.4	88.6	86.5	2.7	0.7	8.8	7.3	8.8	.78	.65	.53	7.8	6.9	8.2	5.1	5.7	4.4	1.1	1.2	1.8
9. Jacksonville Public	92.1	88.1	87.6	2.6	0.7	8.5	6.1	8.9	.65	.69	.45	7.6	7.0	7.3	4.7	5.5	4.2	1.1	.95	1.6
10. New Orleans Public	93.1	91.6	86.9	2.6	0.6	8.5	8.3	8.9	.77	.66	.40	8.3	6.9	8.0	5.6	5.8	4.4	.76	.72	1.53
11. St. Louis Public	92.0	89.8	85.7	3.0	0.9	8.7	7.4	8.8	.85	.74	.66	5.7	5.6	6.3	4.7	5.3	4.1	1.4	1.3	1.92
12. Cincinnati Public	92.8	90.0	86.3	3.0	0.9	8.5	7.7	8.8	.81	.76	.54	5.9	6.1	6.4	4.6	5.3	4.2	1.1	1.2	1.86
13. Cleveland Public *																				
14. Carnegie Pitts. Public	91.1	91.4	85.4	2.6	0.4	8.7	8.3	8.7	.75	.62	.49	6.6	5.5	6.0	4.6	5.2	4.0	1.6	1.8	2.3
15. Crerar Chi.*																				
16. Ames	92.0	90.0	85.5	2.5	0.4	8.7	7.4	8.7	.77	.63	.49	7.9	7.3	8.3	5.0	5.8	4.5	1.1	.92	1.44
17. Butte	92.6	91.5	89.2	2.8	0.7	8.7	7.2	8.6	.67	.65	.48	9.1	7.9	11.7	4.9	5.8	4.3	.74	.74	1.09
18. Colorado College	93.9	93.0	88.7	2.9	0.2	8.5	7.8	8.9	.61	.62	.50	8.0	7.6	9.0	5.8	5.7	4.3	.74	.76	1.42
19. Arizona U.*																				
20. USC L. A.	92.3	91.4	88.7	2.8	0.4	8.2	8.3	8.8	.71	.64	.49	7.5	9.7	8.3	4.8	4.5	4.3	1.0	1.2	1.54
21. Calif. U. Berkeley *																				
22. Seattle Public	94.7	93.2	90.1	3.0	0.8	8.7	8.2	8.9	.85	.73	.55	8.4	7.5	10.3	5.6	5.8	4.5	.85	.87	.89
23. Toronto Public *																				
24. McGill Montreal	92.4	91.5	88.0	2.2	0.3	8.5	8.2	8.8	.69	.58	.47	8.1	7.5	9.0	5.8	5.9	4.4	.72	.78	1.38
25. Dalhousie U., N. B.	93.9	92.7	87.9	3.1	0.7	8.7	7.9	8.7	.71	.61	.48	8.8	8.0	8.8	5.7	5.7	4.3	.81	.72	1.25
Original Values in 1934 (Table II)	95.0	95.4	90.7						2.7	.60	.20				6.4	6.3	5.7	.32	.46	.92

A — American Writing Paper 100% Rag

B — Worthy Paper Mfg. Association 100% Rag

C — Dill & Collins 100% Solka Pulp

* Volume not available for testing.

TABLE V

STRENGTH DATA OF PAPER SAMPLES AFTER USE

	A Basic Wt., lb. 25 x 38	B Basic Wt., lb. 25 x 38	C Basic Wt., lb. 25 x 38	Schopper Fold A In	A Acr.	B In	B Acr.	C In	C Acr.	Schopper Tensile A In	A Acr.	B In	B Acr.	C In	C Acr.
1. Dartmouth College	56.1	71.2	60.8	14	8	9	9	4	2	16.1	9.1	16.5	11.6	11.5	5.6
2. Boston Public *															
3. Columbia University				10	8	7	7	3	2	15.9	9.2	16.7	10.6	11.1	5.1
4. N. Y. Public				9	6	7	7	3	2	15.9	8.2	16.0	10.4	10.0	5.4
5. N. Y. Public *															
6. St. Lawrence U.				14	8	9	9	3	2	16.7	9.5	17.3	12.0	12.4	5.8
7. Library of Congress				11	7	8	8	3	2	16.4	9.4	17.4	11.6	11.5	5.5
8. U. of North Carolina				9	6	7	7	3	2	16.4	9.5	17.2	11.5	11.5	5.6
9. Jacksonville Public	57.3	71.2	61.6	12	9	8	9	3	2	15.8	8.8	16.5	11.6	12.1	5.7
10. New Orleans Public	56.9	72.5	61.5	12	7	9	9	4	2	16.9	9.5	17.4	11.9	12.5	5.8
11. St. Louis Public				8	8	7	8	3	2	15.6	9.1	17.0	11.9	11.7	5.3
12. Cincinnati Public				12	8	9	9	3	2	16.6	9.7	16.7	11.7	11.9	5.7
13. Cleveland Public *															
14. Carnegie Pitts. Public				8	8	8	9	3	1	15.4	9.8	17.0	12.0	12.4	5.4
15. Crerar Chi.*															
16. Ames	57.3	70.8	57.7	12	7	8	8	3	2	17.0	9.6	17.3	11.7	12.0	5.8
17. Butte				13	9	10	9	5	2	17.0	9.7	17.4	11.8	12.5	5.8
18. Colorado College				14	9	11	10	4	2	16.6	9.5	17.5	12.2	12.7	6.0
19. Arizona U.*															
20. USC L. A.	55.4	70.2	61.5	10	8	9	9	4	2	16.6	9.8	17.7	11.8	12.4	5.8
21. Calif. U. Berkeley *															
22. Seattle Public	57.5	71.2	58.3	14	8	10	9	5	2	16.9	9.7	17.3	12.0	12.3	5.8
23. Toronto Public *															
24. McGill Montreal				13	9	9	9	4	2	16.9	10.0	17.5	12.1	13.0	5.9
25. Dalhousie U., N. B.	55.4	68.8	60.4	15	8	9	9	4	2	16.8	9.8	17.0	12.0	12.2	5.8
Original Values in 1934 (Table II)				74.7	48.5	—	—	5.5 av.		—	—	—	—	—	—

A — American Writing Paper 100% Rag

B — Worthy Paper Mfg. Association 100% Rag

C — Dill & Collins 100% Solka Pulp

* Volume not available for testing.

TABLE VI

COMPARISON OF PAPERS *A* AND *C* FROM VOLUMES IN "GOOD" AND "BAD" PHYSICAL CONDITION

	Volume Condition	SR Folding Test		Tensile Test		α-Cellulose		pH	
		A	C	A	C	A	C	A	C
N. Y. Public (4)						90.0	85.0	4.2	4.1
Machine	bad	9	3	15.9	11.1				
Across		6	2	8.2	5.1				
New Orleans (10)						93.1	86.9	5.6	4.4
Machine	fair to poor	12	4	16.9	12.5				
Across		7	2	9.5	5.8				
Iowa State (16)						92.0	85.5	5.0	4.5
Machine	fair to good	12	3	17.0	12.0				
Across		7	2	9.6	5.8				
Seattle Public (22)						94.7	90.1	5.6	4.5
Machine	good	14	5	16.9	12.3				
Across		8	2	9.7	5.8				
Original (as determined by the manufacturer)		74.7	5.5 Av.	No data		95.0	90.7	6.4	5.7

It is thus evident that there is a direct relation between the extent of use and the extent of deterioration. While this might almost be expected, we are now able to show specifically that the books that had been most used, as evidenced by their general appearance, also had the lowest residual strength (as measured by the folding test), the lowest alpha-cellulose content, and the highest acidity.

3. The experience gained in this very laudable research program points to the hazards involved in long-term studies. The first purpose of the program was not fully achieved because the original test methods employed were with one exception not so clearly described as to be capable of reproduction at the end of the test period. The lack of a clear description of methods was more serious than would appear on the surface, for between the beginning and the end of the experiment the standard methods of testing had changed.

The author wishes to express his appreciation to the various members of the staff of the Institute of Paper Chemistry, too numerous to name, who have participated in the testing program. Furthermore, it should be noted that the original test program of the Joint Committee would never have been completed had it not been for the determination of H. M. Lydenberg, whose keen interest in having the study completed and the results made available to librarians and archivists has been responsible for bringing the program to a conclusion and for the writing of this report.

Appendix

For those who may be interested, the following is a description of the physical and chemical tests employed:

1. *Physical Test Methods*

The basis weight was determined on samples taken from the copies numbered 1, 9, 10, 16, 20, 22, and 25. Schopper fold and Schopper tensile were determined on samples taken from the copies numbered 1, 3, 4, 6, 7, 8, 9, 10, 11, 12, 14, 16, 17, 18, 20, 22, 24, and 25. Tests were carried out at 65% RH and 70°F in order to match procedures used in the early thirties. The results of these determinations are shown in Table V. The basis weight determinations were made on unprinted sheets taken from the back of each book. The fold and tensile determinations were made on printed pages. Ten pages for each sample were used, and these were selected at regular page intervals from the various copies. Ten specimens, one from each page, were tested for both directions of the paper.

It should be stressed that the test employed for determining folding endurance is primarily designed for papers of fairly high strength. Just what its significance is on papers of low folding endurance is questionable. As an illustration of this, we checked the folding endurance of the three types of paper on the MIT folding tester at three tensions — the specified tension of 1 kg., a tension of 500 grams, and a tension of 200 grams. From the data we extrapolated to zero tension. (In actual use when a page in a book is folded by a careless reader, the tension is probably very low.) The results appear in the following table.

TABLE VII

FOLDING TESTS FOR COPIES 4 AND 18

	Number of Double Folds to Failure			
Tension:	1 kg.	500 g.	200 g.	Extrapolated
Volume 4 (N. Y. Public Library)				
Sample *A* (American Writing Paper)				
Machine direction	6	32	1031	22,700
Cross machine direction	4	31	774	14,600
Sample *B* (Worthy Paper Co)				
Machine direction	4	19	394	7,300
Cross machine direction	4	24	290	2,200
Sample *C* (Dill & Collins — Solka)				
Machine direction	2	8	70	450
Cross machine direction	1	5	42	260
	Number of Double Folds to Failure			
Tension:	1 kg.	500 g.	200 g.	Extrapolated
Volume 18 (Colorado College)				
Sample *A* (American Writing Paper)				
Machine direction	6	50	1283	17,400
Cross machine direction	5	34	1032	16,000
Sample *B* (Worthy Paper Co.)				
Machine direction	5	25	684	17,900
Cross machine direction	5	28	915	22,000
Sample *C* (Dill & Collins — Solka)				
Machine direction	2	9	148	2,000
Cross machine direction	1	5	76	900

Evidently all three samples still have residual folding strength for some extended period of use. The extrapolated values suggest the need for the development of a special folding test for weak sheets. After the long period of use, the rag sheets, however, are clearly superior to the Solka sheets, under all four tensions with the MIT folding tester. In all probability they were originally superior. (The implied lack of certainty here is due to the fact that we are not certain whether Dill & Collins folds were made with the Schopper tester or with the MIT tester.)

2. *Chemical Test Methods*

1. Alpha cellulose. Method of Bureau of Standards, circa 1930. See Burton, J. O. and Rasch, R. H., Bureau of Standards Journal of Research, No. 6, 603-13 (Jan.-June, 1931). The weight of sample was corrected for starch, rosin, and ash. The weight of alpha cellulose was corrected for ash.

$$\% \alpha = \frac{(\text{wt. of alpha cellulose}) - (\text{ash in alpha})}{(\text{Sample wt. x moisture factor}) - (\text{O. D. sample wt.}) \quad \frac{(\% \text{ ash, starch \& rosin})}{100}}$$

2. Starch. Determined colorimetrically with iodine-iodide following water extraction.
3. Ash. Institute Method 610.*
4. Rosin. Institute Method 604.*
5. Cuprammonium viscosity. Institute Method 420 with the following modifications. (1) The samples were extracted with boiling water in a Waring Blendor and then filtered through a Gooch filter. (2) The samples were then extracted with 95% ethanol, acidified with acetic acid, and finally washed with 95% ethanol. (3) The samples were air dried and fluffed in a Waring Blendor.*
6. Hot water pH. Tappi Method T 435 m 52.*
7. Copper number. Tappi Method T 430 m.*

* The author will be happy to furnish copies of either the Institute or the Tappi Test Method.

COMMENTS ON DR. LEWIS' REPORT

By James L. Gear *

Dr. Lewis and the staff of the Institute of Paper Chemistry have done an excellent job of testing and evaluating the final data from the experiment on the deterioration of book paper. The testing

* Mr. Gear is Chief of the Document Restoration Branch, National Archives.

and subsequent analysis of the data were made difficult by the lack of information on the original test methods and the possible lack of uniformity in the original chemical and physical values of the papers that made up the volumes tested. Although no clear-cut conclusions can be drawn to answer completely and specifically the questions that the experiment was designed to answer, one must agree that some interesting and valuable data were developed.

If a similar experiment were to be initiated today, I should recommend, aside from the obvious control of sample variations and adequate documentation, two additional elements — the testing of calcium-carbonate-filled papers and the use of control samples. The suggestion of including calcium-carbonate-filled papers is based on the work of the National Bureau of Standards and another study in which it was found that papers filled with calcium carbonate were more resistant to natural aging than unfilled papers.[1] Calcium carbonate provides for the absorption and neutralization of acid gases from the atmosphere, thus eliminating most of the deterioration other than that which results directly from use. The Joint Committee may have considered setting aside control samples, to be stored in dead storage in an ideal atmosphere, and then have rejected the plan on the ground that the data would be of little comparative value. I believe, however, that such data would be extremely useful in evaluating and comparing the effect on paper of differences in geographic location, atmospheric condition, and degree of use.

[1] Merle B. Shaw and Martin J. O'Leary, *Effect of Filling and Sizing Materials on Stability of Book Papers* (National Bureau of Standards, *Research Paper* no. 1149); and F. S. Hanson, "Resistance of Paper to Natural Aging," in *Paper Industry and Paper World*, 20: 1157 (Feb. 1939).