Changes In Properties Of Paper On Exposure To Sunlight

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ABSTRACT

Paper is mainly made of cellulose present in lignocellulosic materials. Exposure of paper to direct sunlight is expected to change its properties. The changes brought about have been studied by exposing paper samples to artificial light created in xeno tester. In view of this, a systematic study was undertaken by exposing paper samples directly to sunlight. The study shows that the exposure of paper to sunlight causes loss in strength. The strength loss is maximum in the initial period of exposure as compared to the subsequent periods. Amongst all the papers studied, the executive bond paper showed maximum loss in strength and brightness as compared to other paper samples. Amongst all the strength properties, double fold was affected more whereas burst factor and tensile index were not much affected. Opacity of the paper increased with decrease in pH value. The probable reasons identified for the deterioration of paper due to sunlight exposure were the chemicals present in the additives and bleaching chemicals used in the paper manufacture for improving the appearance and brightness.

Introduction

Paper industry is one of the prominent industries in the world, and paper plays an important role in achieving the social objectives of literacy and communication on one hand and supporting the growth of industrial production and trade on the other (1). Paper and paper products are among the most widely used commodities in our society (2), our day to day life.

Paper is the general name for the substance commonly used for writing or wrapping. The word has been derived from the French word 'Piper' through Latin from the Greek, 'Papuros' (3).

The word paper is used to describe a felted sheet of fibres formed by introducing a water suspension of the fibres onto a fine screen. The water drains through the screen, leaving a wet sheet of paper, which is removed and dried. Additives of one or several kinds are usually introduced before or after the sheet is formed to contribute the desired properties to the paper (4).

It is found that modern writing papers and books tend to have a much shorter life expectancy than books manufactured 100 years ago. This is due to the increased use of wood fibers, the use of chemical additives as well as environmental conditions (2). Thus there is a need for finding the factors affecting the stability and durability of paper.

There are two factors affecting the durability and stability classified as internal and external. Internal factors are established during the manufacture of the paper viz. quality of the fibers, sizing materials, presences of acids and metallic salts and other component of the sheet. External factors are related to conditions during storage and use, viz. temperature, relative humidity, light contaminants in the atmosphere etc. (5)

The effects of light on the mechanical properties of pulp and paper have not been as extensively studied as that of heat. This reflects the more limited use of paper in environments where continued exposure to light is involved. The mechanical properties of paper deteriorate under the influence of light (2). The best method for measuring permanence is sunlight exposure.

In earlier studies, Rapson found that chemical changes brought about by exposure to light also affect the formation of coloured materials by heat and moisture. Therefore, the drop in brightness obtained on exposing pulp and paper to light depends upon the intensity of light, the spectral energy distribution in the light source, and the temperature and humidity during irradiation (6). Whereas Brandon observed light rays shorter than about 300 nm have the most detrimental effect on cellulose (7). As per Wilson, the alum used in the paper is one of the chief causes of degradation (8). Kringstad noticed that lignin is primarily responsible for the rapid yellowing of wood and lignin-rich high yield pulps when exposed to sunlight (9,10). Shahani also observed that the photolytic degradation of paper due to the presence of lignin is observed by the yellowing of newsprint when exposed to sunlight (11).

In the present article attempts have been made to explore the effect of sunlight on the various properties of paper and to study the extent of damage caused to different grades of paper under identical conditions of sunlight exposure and to establish probable reasons for their deterioration.

Materials and Methods

Five paper samples were taken for the study, viz., white printing paper, ledger paper, art paper, executive bond paper and white handmade paper. The last paper was obtained from Handmade Paper Institute,

Pune. The remaining paper samples were purchased from local market.

Each paper sample was divided into five parts. One of these was kept as control. The other four parts were exposed to sunlight for the period of 24, 48, 96 and 192 hours. The exposure was carried out during bright sunny days from 10.00 to 4.00 pm resulting in six hours exposure. Thus, a four day exposure was considered as exposure for 24 hours in the sunlight. All the exposures were carried out during the months of January to April.

All the samples were tested for properties, such as bursting factor, folding endurance, tear factor, tensile index, pH, brightness and opacity as per the standard methods(12,13). The changes in the properties of the paper after exposure to sunlight were noted using Philips XL-30 Scanning Electron Microscope. The paper samples were mounted on SEM stubs using double-sided adhesive tape. They were coated with gold/pollodium in a sputter coater and examined. The instrument was operated at 10 KV accelerating voltage. The magnification used to observe the specimen was 80X and 350X.

Results and Discussion

It was observed from Table 1 that the double fold of the paper is the most affected property amongst all the properties studied. In ledger, art and executive bond papers, losses are almost 15-40 % after 24 hours, whereas in white printing and white handmade papers losses are only 5 %. In some samples, strength loss is more in machine direction while in others, loss is more in cross-direction. In executive bond paper for double folds, the loss in machine direction is 50% and in cross direction 60% for the first 24 hours, which is quite high as compared to other paper samples. Loss in folding endurance of paper reduced after exposure to sunlight as reported by Ritcher (14).

In ledger paper, loss in strength after 24 hours in machine direction was almost 45 % and in cross direction 20 %. But after 192 hours, the loss is up to 85 % in machine direction and 75 % in cross direction with respect to double folds.

In white printing paper, the loss is only 5% in the first 24 hours in both directions. Paper, which showed minimum loss in number of folds after 192 hours, were art paper and white handmade paper.

Table 1: Properties of paper after exposure to sunlight

Sample/Hours	Folding Endurance (No. Of Double folds)		Tear Factor ($mN.m^2/g$)		Burst Factor ($g/cm^2/g/m^2$)	Tensile Index (Nm/g)	
	MD	CD	MD	CD		MD	CD
WPP -control	33	21	97.2	100.6	15.0	31.2	19.6
WPP – 24 h	32	20	95.7	95.7	14.0	30.7	19.5
WPP – 48 h	23	16	92.1	92.1	13.8	30.0	19.1
WPP – 96 h	19	16	85.6	85.6	13.7	29.1	18.6
WPP – 192 h	12	9	80.6	84.1	11.0	27.7	16.8
LP - control	143	45	87.6	100.9	14.7	36.9	23.1
LP – 24 h	81	36	85.1	90.4	13.0	35.8	23.0
LP – 48 h	51	31	82.9	88.3	12.9	35.7	22.4
LP – 96 h	43	20	81.0	81.3	12.8	31.6	21.4
LP – 192 h	22	11	75.2	77.9	10.9	31.2	19.1
AP – control	118	69	65.2	65.2	12.7	38.9	22.6
AP- 24 h	90	55	62.4	63.9	12.4	35.9	20.4
AP – 48 h	78	51	61.2	62.8	12.3	35.7	19.9
AP – 96 h	69	45	61.1	62.6	11.9	33.9	19.2
AP – 192 h	63	41	59.2	62.3	11.8	33.4	19.2
EBP - control	86	73	102.5	106.8	22.2	39.4	29.1
EBP – 24 h	43	29	100.8	104.4	14.7	30.6	21.4
EBP – 48 h	38	25	102.0	102.0	13.8	28.9	20.7
EBP – 96 h	35	22	99.8	99.8	13.2	27.7	19.9
EBP – 192 h	31	20	98.7	99.7	12.7	25.9	18.2
WHMP - control	166	142	177.3	178.7	23.8	33.5	25.8
WHMP – 24 h	161	112	165.9	174.2	22.9	33.1	25.1
WHMP – 48 h	141	97	160.7	168.4	22.6	32.6	25.0
WHMP – 96 h	128	91	157.7	159.9	21.2	32.2	24.9
WHMP – 192 h	111	89	155.5	157.0	20.5	32.0	24.5

WPP- White printing paper, LP- Ledger paper, AP- Art paper, EBP- Executive bond paper, WHMP- White handmade paper.

Tear factor of paper is expressed as the product of tear strength of paper in mN and pendulum factor, divided by basis weight. As shown in Table 1, tear factor of the paper is not much affected by the sunlight as compared to the control sample.

In executive bond paper, in the first 24 hours, there was not much loss in tearing strength, compared to bursting strength and double fold. Ritcher (15) reported that tear strength and tensile strength are less affected than fold test when exposed to sunlight.

In white handmade paper, the loss in tear factor for first 24 hours was more in machine direction. As the period increases from 24 hours to 192 hours, the strength loss was further increased in cross direction than in machine direction.
After 192 hours, the ledger paper shows more loss in strength than any other

paper samples. It is 14 % in machine direction and 23 % in cross direction. White printing paper, was the least affected. In white printing paper, loss in strength in machine direction was 17 % and in cross direction it was 16 %. The paper, which showed minimum loss in tear factor, was executive bond paper than other paper samples. For first 24 hours there was hardly any loss in strength in machine direction while in cross direction the loss was only 2 %. When it was observed after 48 hours, 96 hours and 192 hours there was only 1 % loss after every 24 hours, showing total loss of 4 % in machine direction. In cross direction after 24 hours loss in strength is 5 % which further reduced to 7 % after 96 hours.

It is very clear from Table 1, burst factor of the paper decreased in all the samples as compared to control. There was not much loss in strength observed during the first 24 hours and 48 hours of exposure, but effective loss in strength was seen after 96 hours and 192 hours. In most of the papers, initial loss is quite low, it is almost 2 to 8 % whereas in case of ledger paper it is 12 % for first 24 hours. The executive bond paper shows highest loss in strength for the first 24 hours, which is about 34 % and after 192 hours the strength loss was 43 %. Thus executive bond paper showed a strength loss by 9 % from that at 24 hours to 192 hours exposure. Burst factor was affected to a maximum extent in executive bond paper. Ledger paper and white printing paper showed loss in strength in the range of 21 to 27 %.

In art paper, loss in strength after 24 hours is 3 %, which further reduced to 7 % after 192 hours. Art paper had a better burst factor than other samples.

Table 1, shows that tensile index was not much affected for the first 24 hours in most of the papers as compared to control, except executive bond paper. In executive bond paper, loss in tensile index was 28 % and 26 % in machine direction and cross direction respectively after 24 hours of exposure, which was very high when compared with other paper samples. In other samples, loss in tensile index was in the range of 1 to 9 %. In white handmade paper and white printing paper, loss in tensile index was only 1 % in both machine direction as well as in cross direction. Similarly in ledger paper, in cross direction there was negligible loss in tensile index. It was only 0.5 % in cross direction and 3 % in machine direction. Art paper showed 8 % loss in tensile index in machine direction and 10 % in cross direction.

For first 24 hours there was not much loss in tensile index except in executive bond paper. After 48 hours, the rate of loss in tensile index increases in few paper samples. After 96 hours, the rate of loss in tensile index was almost uniform except in ledger paper, in which there was 10 % loss in machine direction from 48 hours to 96 hours.

After 192 hours in case of ledger paper, there was 16 % loss in tensile index in machine direction and 18 % in cross direction. In art paper, there was not much loss in tensile index. In white printing paper, there was 12 % loss in tensile strength in machine direction and 15 % loss in cross direction after 192 hours. In executive bond paper, tensile index was the most affected in shorter exposure. From 24 hours to 192 hours, there was only 12 % loss in strength in machine direction and 11 % loss in cross direction.

The paper samples, which showed better results for tensile index, was white handmade paper. In this paper, rate of loss in strength was found to be uniform in both directions, and hence found to be a better sample.

Reduction in pH was observed in all the paper samples. This acid formation in paper is due to the chemicals present in paper which on exposure to sunlight in the presence of moisture converts to acid (Table 2). Ultraviolet rays in sunlight and fluorescent lightening promote the oxidation of cellulose fibres and causes rapid paper destruction and thus the reduction in pH often results from an aluminium compound known as alum-rosin sizing which is used as a sizing agent (16).

The second major property of the paper which was affected due to sunlight was brightness. It was observed that there was maximum loss in brightness value only for the first 24 hours of exposure as compared to control (Table 2).

Table 2: Properties of paper after exposure to sunlight

Sample/Hours	pH	Brightness (%)	Opacity (%)
WPP - control	5.1	77.3	100.0
WPP – 24 h	4.3	66.3	101.4
WPP – 48 h	4.4	65.0	102.1
WPP – 96 h	4.2	62.8	102.7
WPP – 192 h	4.2	62.8	103.0
LP - control	4.7	44.1	100.0
LP – 24 h	4.2	43.5	100.3
LP – 48 h	4.2	43.4	100.7
LP – 96 h	4.2	43.3	100.9
LP – 192 h	4.0	42.9	101.2
AP - control	8.9	83.6	100.0
AP – 24 h	8.7	77.2	101.1
AP – 48 h	8.7	74.8	101.1
AP – 96 h	8.6	69.6	101.1
AP – 192 h	8.4	69.2	101.7
EBP - control	8.6	93.3	100.0
EBP – 24 h	8.4	77.9	100.3
EBP – 48 h	8.4	74.6	101.5
EBP – 96 h	8.4	65.1	101.6
EBP – 192 h	8.3	63.8	102.3
WHMP - control	4.6	78.6	100.0
WHMP – 24 h	4.4	62.8	101.7
WHMP – 48 h	4.3	62.3	102.4
WHMP – 96 h	4.1	61.7	102.9
WHMP – 192 h	4.3	60.1	102.0

WPP- White printing paper, LP- Ledger paper, AP- Art paper, EBP- Executive bond paper, WHMP- White handmade paper.

Amongst all the paper samples executive bond paper recorded least reduction that is from 93 % to 78 % after 24, hours. On further exposure to another 24 h, the loss was only 4 %. Similarly white printing paper, art paper and white handmade paper showed higher loss in brightness value for the first 24 hours. Ledger paper which was green in shade was the least affected in the first 24 hours. Executive bond paper showed 15 % loss in brightness in 24 and 192 hours, where as all other papers showed only 2 to 4 % loss and 10 % loss in art paper.

Table 2, shows that there was only a negligible reduction in opacity on exposure upto 24 hours.

Scanning Electron Microscopy

Since the loss in strength was maximum in case of executive bond paper, SEM was carried out only on this sample.

In control sample at lower magnification fibres appear to be in criss-cross pattern, while at higher magnification many fibres are flattened and appears like a sheet.
This is due to the pressing process during the paper making. After exposure to sunlight to 24 h, it was observed that flattened sheet like fibres are not much visible, and only individual fibres are seen clearly. This may be due to some changes in the structure of flattened fibres. As the exposure period increases more individual fibres than sheets of fibres are observed. These observations suggest that there was loss in the bonding materials.

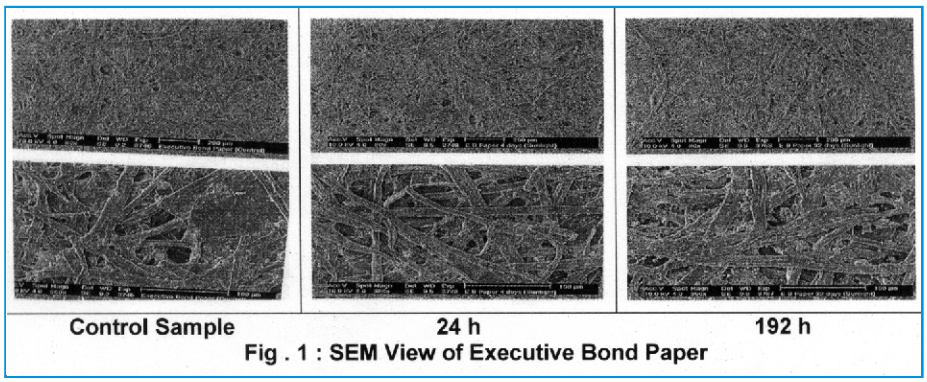

Fig . 1 : SEM View of Executive Bond Paper

Conclusions

1. The study shows that the exposure to sunlight causes loss in strength. The strength loss was maximum in the initial period of exposure as compared to the subsequent period.
2. Double fold of the paper was most affected amongst all the strength properties.
3. In most of the papers, burst factor and tensile index were not much affected in the first 24 h.
4. All the white paper shows maximum loss in brightness value for initial period only and tends to become yellow.
5. Deterioration was much less in white handmade paper compared to other papers.
6. There was a decrease in pH values in all the samples.
7. All the paper samples showed increase in opacity.

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References

(1) **Shaikh A. J. - Microbiological pretreatment of lignocellulosic materials for preparation of pulp for various end uses, pH.D. Thesis, University of Mumbai. (2000)**

(2) Luner P. - Paper Permanence, Tappi J. **52 (5):** 796-806. (1969)

(3) Powale R. A. - Utilisation of textile waste for paper making by chemical and bio-chemical process- A comparative study. M.Sc. Thesis, Nirmala Niketan College of Home Science. (2001)

(4) Browning B. L. - Analysis of Paper, 2nd Edition, Revised and Expanded, pg. 1. (1977)

(5) Browning B. L. and Wink W. A., Studies on the Permanence and Durability of Paper", Tappi J., **51(4)**:156 (1968)

(6) Rapson W. H. and Spinner I. H., The Bleaching of Pulp, Chapter 14, Brightness reversion in Bleached Pulps, 3rd ed, Ed. R. P. Singh, Tappi Press, Atlanta, pg 361 (1979)

(7) Brandon C. E., "Pulp and Paper Chemistry and chemical Technology", Chapter 21, Properties of Paper, 3rd Edn., **III.** Ed. J. P. Casey, Wiley-Interscience Publication, New York, Pg. 1911 (1980)

(8) Wilson W. K. and Hebert, "Evaluation of Stability of Record Papers", Tappi J., **52(8)**: 1523 (1969)

(9) Kringstad K. P. and Lin S. Y., "Mechanis, in the Yellowing of High Yield Pulps by Light" Tappi J., **53(12)**: 2296 (1970)

(10) Kringstad K. P. "degradation of Wood and High-Yield Pulps by Light", Tappi J., **52(6)**: 1070 (1969)

(11) Shahani C. J., http://www.clir.org/pubs/reports /dirsci/dirsci.html, "Effect of Lignin Content on the Aging of Paper", March 1990

(12) TAPPI Standard **T-403, T-414, T-452, T-494, T-511** : standards and suggested methods, Technical Association of Pulp and Paper Industry, New York.

(13) Bureau of Indian Standard, **IS : 1060 (Part 1)** : 10.2 and 16.2 (1966).

(14) Ritcher, A. Relative Permanence of Paper exposed to Sunlight, Ind. Eng.Chem. **27:** 177. (1935)

(15) Ritcher, A. - Relative Permanence of Paper exposed to Sunlight, Ind. Eng.Chem. **27:** 432. (1935)

(16) Lener, D. J. Identifying the Enemies of Paper Part 1, Ancestry Magazine, **12 (3).** (1994)