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EFFECT OF SODIUM ASCORBATE ON WEATHERING PERFORMANCE OF NaOH PULPING AND PAPER

This study aimed to decelerate the weathering of paper from light by utilizing the antioxidant property of sodium ascorbate (SA), which is an ascorbic acid salt. Three different sessions of cooking were carried out by adding 2.5%, 5.0% and 7.5% of SA in proportion to the weight of a completely dried chip in addition to 24% NaOH in order to identify the influence of SA on cooking. It was observed that the pulp yield decreased when SA was added to the cooking. For that reason, it was decided to add SA into the control pulps instead of adding the digester. The same amount of SA was added to the control. The SA-added pulps were held in the agitator initially first for 2 hours and then 12 hours before making paper. So as to determine the influence of the treatment on the process. The paper was treated for 72, 144 and 256 hours and values of ΔL, Δa, Δb and ΔE were identified in order to determine the period of the SA's efficacy against weathering. The total discoloration in all the samples of paper, displayed an increase with an extension of the time period. The lowest discoloration after a 256-hour time period was seen in the sample group where 7.5% of SA was added and soaked in the water. The final results indicated that the most appropriate concentration was 5% and that pulp suspension must be retained for 12 hours to improve mechanical properties.

Keywords: paper, pulp, UV, accelerated weathering

Introduction

Paper can be manufactured as durable or nondurable types, depending on the intended use. For example, sanitary paper is used and must be nondurable, while writing paper is intended to be long-lasting. Paper is exposed to various external influences in long-term use. In particular, valuable paper and book paper should be durable against external influences. External influences may come as one or several types of physical, mechanical, chemical or biological factors. Chang et al. [2002] stated that the chemical properties of their samples experienced

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changes after photo-irradiation for 1, 2, 4, 8 and 12 days by covering them with softwood (hinoki) and hardwood (maple) aromatic and aliphatic film coating.

Researchers have found that there are decreases in the physical properties of paper such as its whiteness and DP with the influence of water, steam above 175°C and depending on the duration of that influence [Vanska et al. 2014]. The oxidation of paper protected from other influences arises from its exposure to air and radiation. As a result, paper ages as it experiences physical and eventually, chemical changes. The weathering process may last as long as a lifetime without traceability, depending on its type and where it is used. Thus, it is necessary to have prior knowledge about the weathering of paper for proper and successful use. As such, accelerated weathering tests are utilized to investigate weathering. Itrić et al. [2015] suggested that an accelerated weathering test, is a fast and inexpensive method to have prior knowledge about possible optical changes in the aging of paper during storage, although it is not perfectly reliable. Zou et al. [1996] put forth that such tests are reliable for estimating the durability of paper.

Cellulose, hemicelluloses, lignin and other added substances exist naturally in paper and undergo different changes when exposed to light. Paper or a paper sheet may be produced as dark or light based on the raw material that it is made up of or due to the production method. In a study by Cademartori et al. [2015] it is stated that dark colours are a result of lignin in the raw material. For instance, all the composite boards that consist of lignin were dark in colour. A coniferous tree (softwood) containing lignin is dramatically discoloured after accelerated oxidation of thermomechanical pulp (TMP) fibres, although it is consistently resistant [Yu et al. 2015]. In the accelerated autoxidation of the paper made up of the lignin-free white spruce pulp, the whiteness of the fibres was maintained, but resistance is remarkably weakened. Lignin protects cellulose against UV, and as such, the discoloration of pulp containing lignin, results in no loss of resistance and lignin also has a protective property [Schmidt et al. 1995].

Baar et al. [2015] remarked that colour parameters turned out to be significantly different statistically, after exposing Hevea and Jabota wood samples to artificial sunlight and a conditioning process. The changes were not visible to the human eye; and the difference might result from the anisotropic property of the wood, and as such would be unimportant. The anisotropic property disappears along with the individualization of fibres in making pulp. However, sapwood and heartwood are morphologically and chemically different from one another. This difference will also influence the papers produced. Therefore, it is more favourable to use one certain type of chip obtained from wood with the same properties in order for the pulp to be homogenous.

Different oxidations of the same paper can also be observed since heartwood is darker than sapwood. This difference may cause fluctuation of the results in an accelerated weathering test. The sapwood of *Cerasus avium* was selected in this study in order to prevent this occurrence. The study aimed to decelerate the

weathering of paper exposed to UV light by utilizing SA, which is a mineral salt of ascorbic acid that has an antioxidant function.

Materials and methods

This study utilized the sapwood of *Cerasus avium* (L.) Monech. *Prunus avium* L. is an economically important species with varieties bred to produce sweet cherries in orchards, ornamental forms, and wild cherry types which yield valuable timber for cabinet making. Most of the wild cherry planted in European woodland derives from seed, which is variable and unimproved genetically, resulting in unpredictable and suboptimal yields [Hammatt and Grant 1998]. Sodium ascorbate is one of a number of mineral salts of ascorbic acid (vitamin C). The molecular formula of this chemical compound is $C_6H_7NaO_6$. As the sodium salt of ascorbic acid, it is known as a mineral ascorbate. It has not been demonstrated to be more bioavailable than any other form of vitamin C supplement. Sodium ascorbate normally provides 131 mg of sodium per 1,000 mg of ascorbic acid (1,000 mg of sodium ascorbate contains 889 mg of ascorbic acid and 111 mg of sodium). The pH must be high for the delignification of lignin in making pulp through alkali methods. Salt is preferred to prevent acid from excessively consuming alkali NaOH. NaOH is preferred as a cooking agent because of the fact that this method produces whiter paper compared to other methods and as it is easy to follow the process of oxidation. For this purpose, three cooking sessions were carried out by using 24% NaOH (Control:C). Additionally, three cooking groups were made by adding 2.5%, 5.0% and 7.5%, respectively, of SA in the digester, in addition to 24% NaOH (AD), to estimate the effect of SA on cooking conditions. Sodium ascorbate was added at two different stages. For the companion, Na-ascorbate was added to the pulp and also it was added during cooking. For the two groups, brightness values were measured for colour properties rather than the Kappa number. To see how the Na-ascorbate affects the original colour of the pulp after accelerated weathering, no bleaching procedure was carried out. By measuring the pH of the black liquor taken out of the digester, the decrease caused by the SA was estimated. It was determined that the addition of SA in the cooking process would not be appropriate since pulp yields decreased in accordance with the pH decline. For that reason, 2.5%, 5.0% and 7.5% of SA were added into the control pulp and kept in the agitator for 2 hours (HA2) and 12 hours (HA12). The differences between each of them were identified by producing paper from these pulp samples.

For the individualization of the fibres were screened by Somerville type equipment [TAPPI T275:2002].

Pulp production parameters were as follows; cooking temperature as 170ºC, time to reach the cooking temperature was 90 min. Total waiting time out at cooking temperature was 90 min., the total cooking procedure was 180 min.

Before and after a weathering test for the produced paper, the values of opacity, brightness, breaking length, burst strength and tensile properties were measured according to the following standards, respectively, TAPPI T494 om-01:2001, TAPPI T519 om-02:2002, TAPPI T525 om-02:2002, TAPPI 403 om-02:2002.

Accelerated weathering tests (QUV)

UV-light irradiation tests were conducted in an accelerated weathering test chamber for periods of 72, 144 and 256 hours where the estimated temperature was 50°C and the average level of irradiance was 0.65 W/m^2 at 340 nm [ASTM G154:1998].

Colour measurements

Colours were measured according to ISO 7724-2:1984 standards. In CIE $L^*a^*b^*$, there are three axes that signify lightness and chromaticity. L^* represents lightness (100 refers to white and 0 refers to black), whereas a^* and b^* describe 4 different colours at each extremity: $a^* > 0$ signifies red, $a^* < 0$ green, $b^* > 0$ yellow and $b^* < 0$ blue. Before and after the weathering test, sample colours were measured by a colour measurement device of D65 illuminant. Equations (1), (2), (3) and (4) measure colour values change ΔE^* during UV irradiation.

$$\Delta L^* = Lf^* - Li^* \tag{1}$$

$$\Delta a^* = af^* - ai^* \tag{2}$$

$$\Delta b^* = bf^* - bi^* \tag{3}$$

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \tag{4}$$

ΔL^*, Δa^* and Δb^* represent changes of the values obtained before and after the exposure. A low ΔE^* refers to a slight change or constancy in colour ISO 7724--2:1984].

Glossiness

A Konica Minolta Multi gloss 268 plus meter was used to measure gloss and a progressive loss of gloss refers to the initial symptoms of weathering. Reflected radiation was at an angle of 60 ±0.1° according to ISO 2813:1994 and each sample was tested three times in line with the direction where the radiation was reflected [ISO 2813:1994].

Results and discussion

The screened yields, screenings and total yields of the pulps added 24% NaOH (Control) and 24% NaOH + SA(AD) and their pH values in the black liquor are shown in table 1.

Table 1. Pulp yields of the sapwood of *Cerasus avium* (L.) Monech and the pH values in the black liquor

Cooking conditions	Screened yield (%)	Reject (%)	Total yield (%)	pH
24%NaOH (C)	44.34	0.56	44.90	12.72
C+2.5% SA (AD)	42.66	4.73	47.39	12.57
C+5.0% SA (AD)	42.00	3.89	45.89	11.55
C+7.5% SA (AD)	32.11	17.05	49.16	10.63

C – control, AD – added in the digester.

Adding SA in the cooking liquor reduces yields compared to the control cookings. With added SA, lower yields also led to the proportional decrease of pH values in the black liquor. The added SA apparently results in lower yields because it weakens the activeness of NaOH.

SA additions in the digester during the production of paper L^* was decreased, the a^* value was unchanged, and the value of b^* increased. Other factors, such as with addition of SA, left L^* and a^* unchanged, while the b^* value increased. The increasing rate of SA L, a, b values showed changes in table 2, but these changes were not statistically significant. The lack of change in the colour of the paper was a positive result for the addition of SA since the aim of this study was to provide colour stability.

Table 3 shows ΔL, Δa, Δb ve ΔE values for the following kinds of paper prior to and following their exposure to weathering for 72, 144 and 156 hours: control (24% NaOH), additions in the agitator (24% NaOH+ 2.5%, 5.0% vs. 7.5% SA) and control (24% NaOH) + additions in the agitator (for 2 and 12 hours 2.5%, 5.0% vs 7.5%)

In the CIE $L^*a^*b^*$ colour system (Commission Internationale de I' Eclairage), colour differences and their spaces are identified according to $L^*a^*b^*$ colour coordinates. Here, the L^* axis represents black or white ranging from 0 to 100 (100 is completely black, while 0 is white). The axis a^*, either end of which represents red (+) or green (-), and b^* has yellow (+) at one end and blue (-) at the other [Sivrikaya et al. 2015].

While cooking, a 2.5% SA addition, increased the ΔL value compared to control samples in the treatment period for 2 hours and 12 hours. The increase in the ratio of SA caused a decline, but this was not found to be important. In this case, SA did not influence discoloration.

After the paper was subjected to UV irradiation, SA was added at various rates and time periods for 72, 144 and 256 hours. The discoloration values are displayed in table 2. In line with the added time for each sample group, the ΔL value increased; that is, there was a tendency towards a white colour in the paper samples. In the paper samples where SA was added, the least change in the value of ΔL (8.85) after an accelerated weathering test for 256 hours was seen in the samples produced after the treatment period in the water for 2 hours with the addition of 2.5% SA. The major change was encountered in the control samples in which no SA was added (ΔL: 10.41). The discoloration in ΔL shows the bleaching of paper samples. After a test for 256 hours, the ratio of SA added in

Table 2. The before weathering *L*, *a*, *b* values of the paper as a result of adding SA after the control, additions in the digester and additions in the agitator

			Before test
C		*L*	61.45 (0.70)
		a	7.39 (0.13)
		b	11.97 (0.06)
C + AD	2.5%	*L*	58.24 (0.22)
		a	7.69 (0.11)
		b	12.84 (0.12)
	5.0%	*L*	58.56 (0.13)
		a	7.08 (0.06)
		b	13.01 (0.04)
	7.5%	*L*	57.45 (0.26)
		a	7.84 (0.22)
		b	13.78 (0.25)
C + HA2	2.5%	*L*	60.99 (0.09)
		a	7.21 (0.06)
		b	12.07 (0.07)
	5.0%	*L*	61.18 (0.16)
		a	7.05 (0.07)
		b	12.07 (0.06)
	7.5%	*L*	61.34 (0.10)
		a	7.02 (0.03)
		b	12.19 (0.04)
C +HA12	2.5%	*L*	61.04 (0.23)
		a	6.94 (0.06)
		b	11.99 (0.13)
	5.0%	*L*	61.15 (0.11)
		a	6.99 (0.08)
		b	12.01 (0.07)
	7.5%	*L*	61.55 (0.14)
		a	6.82(0.0)
		b	12.21 (0.07)

AD – added in the digester, HA2 – 2-hour-holding in agitator, HA12 – 12-hour-holding in agitator. The values in the parentheses are standard deviations.

Table 3: The after weathering ΔL, Δa, Δb ve ΔE values of the paper as a result of adding SA after the control, additions in the digester and additions in the agitator

			72 hours	144 hours	256 hours
C		ΔL	6.37 (0.22)	8.24 (0.41)	9.16 (0.42)
		Δa	-1.69 (0.17)	-1.94 (0.03)	-2.07 (0.04)
		Δb	3.40 (0.04)	3.64 (0.09)	3.82 (0.04)
		ΔE	7.42 (0.22)	9.22 (0.35)	10.14 (0.37)
C + AD	2.5%	ΔL	6.91 (0.18)	8.60 (0.40)	9.98 (0.10)
		Δa	-1.78 (0.07)	-2.01 (0.17)	-1.94 (0.05)
		Δb	3.66 (0.11)	3.81 (0.26)	3.68 (0.06)
		ΔE	8.02 (0.21)	9.63 (0.33)	10.81 (0.09)
	5.0%	ΔL	6.68 (0.21)	8.18 (0.13)	9.53 (0.09)
		Δa	-1.50 (0.04)	-1.59 (0.03)	-1.65 (0.07)
		Δb	3.42 (0.07)	3.65 (0.05)	3.16 (0.08)
		ΔE	7.65 (0.18)	9.09 (0.12)	10.17 (0.07)
	7.5%	ΔL	6.55 (0.22)	8.11 (0.44)	9.30 (0.17)
		Δa	-1.75 (0.30)	-1.68 (0.12)	-1.58 (0.04)
		Δb	3.71 (0.23)	2.57 (0.22)	4.03 (0.12)
		ΔE	7.73 (0.21)	9.46 (0.64)	10.81 (0.09)
C + HA2	2.5%	ΔL	6.17 (0.07)	7.79 (0.10)	8.85 (0.15)
		Δa	-1.45 (0.03)	-1.68 (0.04)	-1.67 (0.03)
		Δb	3.35 (0.02)	3.66 (0.05)	3.30 (0.03)
		ΔE	7.16 (0.06)	8.76 (0.11)	9.59 (0.14)
	5.0%	ΔL	6.10 (0.24)	7.52 (0.15)	8.84 (0.06)
		Δa	-1.33 (0.14)	-1.48 (0.02)	-1.55 (0.02)
		Δb	3.35 (0.12)	3.59 (0.04)	3.11 (0.03)
		ΔE	6.88 (0.19)	8.46 (0.14)	9.49 (0.06)
	7.5%	ΔL	5.78 (0.15)	7.26 (0.13)	8.75 (0.09)
		Δa	-1.28 (0.02)	-1.46 (0.08)	-1.53 (0.02)
		Δb	3.24 (0.18)	3.42 (0.03)	3.13 (0.03)
		ΔE	6.96 (0.17)	8.15 (0.12)	9.42 (0.09)
C + HA12	2.5%	ΔL	5.97 (0.17)	7.69 (0.28)	8.75 (0.12)
		Δa	-1.20 (0.06)	-1.41 (0.07)	-1.39 (0.11)
		Δb	3.11 (0.08)	3.36 (0.08)	3.58 (0.11)
		ΔE	6.83 (0.18)	8.51 (0.27)	9.55 (0.09)
	5.0%	ΔL	6.08 (0.10)	7.55 (0.22)	8.47 (0.12)
		Δa	-1.35 (0.08)	-1.42 (0.06)	-1.51 (0.04)
		Δb	3.21 (0.09)	3.31 (0.02)	3.45 (0.09)
		ΔE	7.00 (0.11)	8.36 (0.20)	9.27 (0.09)
	7.5%	ΔL	5.83 (0.09)	7.32 (0.13)	8.18 (0.08)
		Δa	-1.19 (0.09)	-1.26 (0.04)	-1.36 (0.01)
		Δb	2.96 (0.12)	3.03 (0.03)	3.2 (0.02)
		ΔE	6.65 (0.13)	8.02 (0.12)	8.88 (0.07)

AD – added in the digester, HA2 – 2-hour-holding in agitator, HA12 – 12-hour-holding in agitator.

the water was unimportant and the change of ΔL was lowered along with the added SA during treatment in water for 2 hours.

When a^* and b^* values were examined for paper samples, there was a tendency towards $-a$ (green) and $+b$ (yellow). The least change in a^* values was seen in the samples produced by adding 7.5% of SA treated in the water while the biggest change was seen in the control samples. Among the control samples after the accelerated weathering test for 144 hours and 256 hours, there were no significant differences in terms of a^* values. The samples treated in water for 12 hours showed more resistance against weathering compared to those treated for 2 hours and with added SA in the digester. In this case, the extension of the added time of SA in the pulp increased a^* stability. For the b^* value, the sample results are presented in Table 2, and tended to turn yellow and display a better resistance against discoloration thanks to the SA addition in the water for 12 hours after a total of 256 hours compared to other groups.

Paper samples undergo dramatic changes at both the macro and micro levels through the acid in the paper, atmospheric oxygen, microorganisms and the influence of light. The primary change at the macro level is that the samples lose their original colour [Princi et al. 2008]. In line with added time, the total discoloration in each variation of paper sample also increased. After a period of the first 72 hours and the last 256 hours, the least discoloration was observed in the sample group with the addition of 7.5% SA (ΔE: 6,65-8,88) and with treatment in water. The biggest change was encountered in paper samples with the addition of 2.5% SA in the digester (ΔE: 8,02-10,81). This is apparent in table 3, showing that in parallel with an increase in added SA in all the variations, total discoloration showed a decrease.

Table 4. The pre-aging and post-aging brightness values of the paper after adding SA in the control, digester and agitator

SA %		0 hour	72 hours	144 hours	256 hours
C 0.0		3.71 (0.10)	4.19 (0.15)	4.32 (0.14)	4.33 (0.23)
C + AD	2.5	3.76 (0.07)	4.20 (0.00)	4.33 (0.06)	4.40 (0.10)
	5.0	3.70 (0.11)	4.20 (0.10)	4.20 (0.00)	4.30 (0.10)
	7.5	3.71 (0.14)	4.13 (0.06)	4.23 (0.12)	4.17 (0.15)
C + HA2	2.5	3.97 (0.08)	4.30 (0.00)	4.45 (0.07)	4.60 (0.00)
	5.0	4.04 (0.12)	4.47 (0.06)	4.43 (0.15)	4.53 (0.12)
	7.5	3.98 (0.17)	4.35 (0.21)	4.35 (0.07)	4.50 (0.14)
C + HA12	2.5	3.66 (0.12)	3.97 (0.06)	4.20 (0.10)	4.13 (0.15)
	5.0	3.61 (0.03)	3.93 (0.06)	4.07 (0.06)	4.13 (0.12)
	7.5	3.60 (0.05)	3.93 (0.06)	4.07 (0.06)	4.17 (0.06)

The values in the parentheses are standard deviations.
C – control, AD – added in the digester, HA2 – 2-hour-holding in agitator, HA12 – 12-hour--holding in agitator.

An increase in the brightness of control samples caused by accelerated weathering. There is a tendency towards the colour white on the surface of the paper along with weathering. As a result of this, the brightness values of sample surfaces showed an increase. Each variation displays the same result. The paper produced by adding 2.5%, 5.0% vs. 7.5% SA for 12 hours in the agitator showed a decrease in brightness. A slight increase is seen in other variations.

Table 5. The pre-aging and post-aging tearing values of the paper after adding SA in the control, digester and agitator

Tearing (mNm^2/g)				
SA (%)	0 hour	72 hours	144 hours	256 hours
C (0.0)	2.12 (0.21)	2.08 (0.05)	2.08 (0.24)	2.06 (0.05)
C+AD (2.5)	2.14 (0.28)	2.13 (0.10)	2.07 (0.02)	2.05 (0.11)
C+AD (5.0)	2.26 (0.25)	2.20 (0.01)	2.07 (0.01)	2.04 (0.16)
C+AD (7.5)	2.15 (0.30)	2.05 (0.05)	2.01 (0.15)	2.01 (0.03)
C+HA2 (2.5)	2.23 (0.14)	2.16 (0.02)	2.11 (0.04)	2.09 (0.00)
C+HA2 (5.0)	2.30 (0.14)	2.13 (0.02)	2.09 (0.07)	2.07 (0.22)
C+HA2 (7.5)	2.17 (0.03)	2.19 (0.00)	2.09 (0.02)	2.05 (0.04)
C+HA12 (2.5)	2.21 (0.00)	2.20 (0.21)	2.18 (0.12)	2.14 (0.01)
C+HA12 (5.0)	2.25 (0.10)	2.18 (0.19)	2.13 (0.05)	2.09 (0.02)
C+HA12 (7.5)	2.17 (0.12)	2.13 (0.27)	2.12 (0.34)	2.13 (0.22)

C – control, AD – added in the digester, HA2 – 2-hour-holding in agitator, HA12 – 12-hour--holding in agitator.
The values in the parentheses are standard deviations.

Compared to the control samples, 2.5% and 5% SA addition, enhanced the tearing resistance of paper. Yet, adding 7.5% SA caused the tearing resistance to drop to a level close to that of the control samples. There were decreases in resistance up to 72 and 144 hours of accelerated weathering, but there was no significant decrease in the 256-hour treatment period compared to that of 144 hours.

The addition of 2.5% and 5% SA, compared to the control samples, increased breaking resistance. However, 7.5% SA addition lowers tearing resistance. There is a decrease up to 72 hours and 144 hours, but no significant decrease at 256 hours in the accelerated weathering.

Lower values from the control samples were obtained when SA was added to the digester. In comparison, when SA was added to the control pulps, the values increased and reached a peak (3.00) with a 5% concentration. After 12-hour--holding in the water, the fastness was the highest (2.89) after a 256-hour--weathering test under the same conditions.

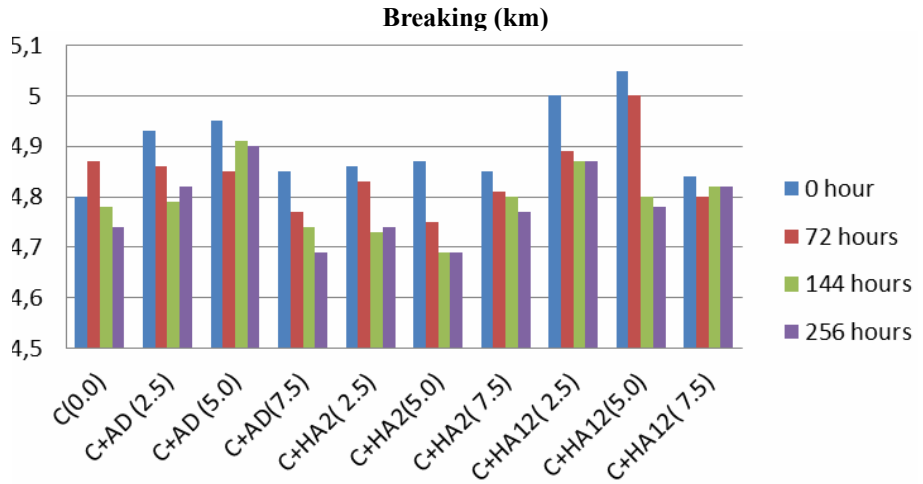

Fig. 1. The pre-aging and post-aging breaking values of the paper after adding SA in the control, digester and agitator

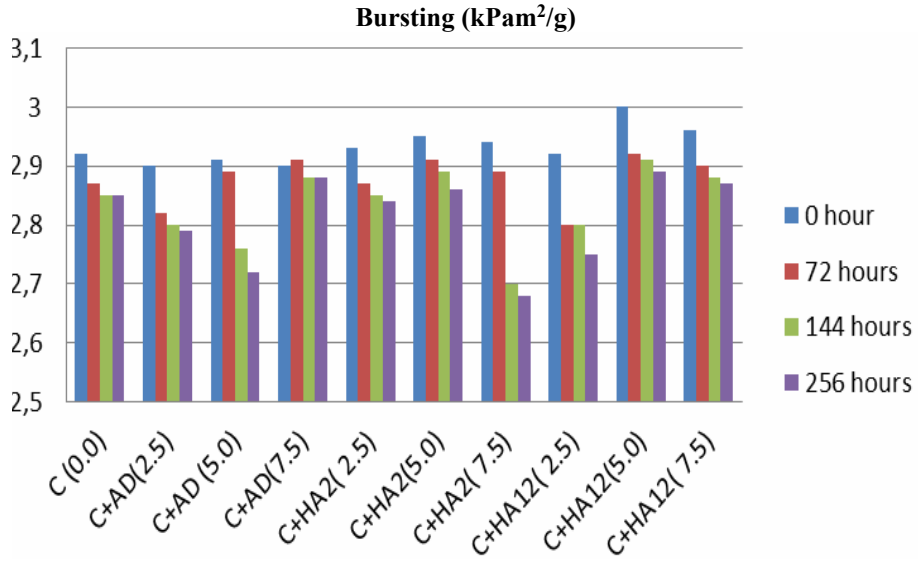

Fig. 2. The pre-aging and post-aging bursting values of the paper after adding SA in the control, digester and agitator

The SA ratio has no significant effects on burst strength values. There was a noticeable drop as a result of increasing accelerating weathering hours from 0 to 72. An extension of the period showed no significant changes.

Prince et al. [2008] suggested that the surface of cellulose will experience degradation, however, this will not influence the interior parts and so there will be no morphological changes while storing the paper in the dark for a long period.

They also put forth, however, that UV penetrated into cellulose, which will result in mechanical degradation. The study shows that 340 nm UV used in the study has an effect to a certain extent on the mechanical properties inside the paper and no effects on mechanical properties from this extent on. The more advanced mechanical properties of SA-added paper compared to that of the control sample means that SA increase mechanical resistance. Additionally, the more advanced mechanical properties of the SA-added samples over the control samples after UV application shows that sodium ascorbate has protective characteristics against UV. This suggests that light at this wavelength does not influence mechanical degradation after a certain period of time.

Conclusions

SA should not be added in the digester during the cooking process because this decreases the activeness of alkali. The addition of 5% SA in the agitator can be used as it improves the mechanical properties of paper. The least change in the value of ΔL after an accelerated weathering test was encountered in paper samples that were produced by adding 2.5% SA with treatment in water for 2 hours. The highest change was seen in control samples that did not have the addition of SA. Therefore, the addition of 2.5% SA provides improved colourfastness.

Examining the weathering process in terms of time period, the burst strength decreased after extending the period up to 72 hours, but this time extension did not display a significant change. Thus, the weathering weakens the burst strength up to 72 hours and it has no effects after this point of time.

The tearing and breaking values of paper decreased up to 144 hours. However, no significant changes were encountered between a 256-hour weathering test and a 144 hour test. As such, UV application of 340 nm wavelength for 144 hours reaches the internal surface of the paper and identifies the loss of tearing and breaking resistance. For such reasons, we are of the opinion that 5% SA should be added into pulp for 12 hours to improve the mechanical properties of paper.

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TAPPI T494 om-01:2001 Tensile Properties of Paper and Paperboard

TAPPI 403 om-02:2002 Bursting strength of paper

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