Original Research Article

Treatments of Recycled Pulps from Old Corrugated Containers. Part I. The Effects of Boron Compounds on Optical and Physical Properties

ABSTRACT

It has been found that the bulkiness of paper produced from sodium borohydride treated secondary pulps show higher bulk values than that of the control and boric acid process in the same phase. The highest bulk value of 3.41 cm^3/gr was found with 10% sodium borohydride treated pulps at the fifth recycle phase. However, bothboroncompoundspositivelyeffect on OldCorrugatedContainer (OCC)secondary fibers regarding water absorption properties (Cobb value) of test papers. The highest water absorption value of 135 g/m^2, was observed in 10% boric acid treatment conditions at fifthrecyclingstagethatwasapproximately8.0% and 26.16% higherthantheformerrecycledpapersandcontrol at thesamerecyclingphase, respectively. Test paperstreatedwithbothcompoundshaveshowed in marginallimitsfor total colordifferences (ΔE) regardless of chemicaltretamentandrecyclingphase. Itwasrealizedthattheselectedboroncompoundsusedfortreatmentof OCC secondaryfibersdid not cause significant changes in the color and optical values.

Keywords: Old Corrugated Container, recycling, boric acid, sodium borohydride, water absorption, paper color, brightness

INTRODUCTION

Priortotheinvention of paper, peopleutilizedclaytablets, treebarks, animal skins, and papyrus plant for communication and writing purposes. However, one of thefirstcellulosebasedwritingmaterialproducedfrompapyrusplants, whichnaturallygrewup in Egyptsince pre-historictimes. Thereby, the English name of paper has belived to derive from that plant [1,2].The paper that we have used in modern time was invented by Ts'ai Lun at 105 A.D, in China. Since the invention of paper, it hasbecomeone of the most important communication and social tools. [1-3].

However, the needs of paper based products increased every year. But the main cellulose source of forest lands has become important and very valuable sources for human beings. Inthis sense, the idea of preservationofthosesourceshavebecome an importantissuethattheyshould be carefullyutilizedandifpossible not muchconsumed for forest products and paper industry. For that reason, the alternative cellulose sources for paper industry have become emerging topic. In this regard, the post consumer waste paper products could be an alternative raw material source for paper industry due to cellulose fibers readily available in their structure [1,2].

The physical and strength properties of paper based products are important for its aesthetic value and end use places. However, paper made from recycled fibers (i.e. post consumer papers or OCC) has a characteristic gray appearance without deinking process. Inthis sense, a chemicalcompoundthatutilized in recycling of paperproducts is important considering improving not only strengths but also optical properties and aesthetic values.

It has already well established that the high yield pulps (mechanical) shrink less than that of low yield or bleached pulp (chemical) upon drying [4-6]. This is most due to the fact that the presence of lignin between cellulose microfibrils prevents direct contact among fibrils when bound water is evaporated. However, lignin also prevents the formation of hydrogen bond cross-linking between cellulose microfibrils [7]. But, the cracking of dried fibers and formation of further intra-hydrogen bonds that partially irreversible are the effects on strength loss of sheets. Thereby, these irreversible intra-hydrogen bonds should need to be broken during recycling in order to regain fiber bonding potential [8].

Chemical treatment of pulp is a common way to increase and regain the bonding potential of dried pulps. Numerouschemicaltreatmentshavebeenevaluatedforvarioustypeofsecondarypulps (recycling). But, the most common chemical used for improving bonding potential of pulp was reported to be alkaline based chemicals [9-11]. Itwasproposedthatthesodiumhydroxidetreatmentimprovestheswellingcapacity of driedThermoMechanicalPulp (TMP), but does not affectthose of chemical pulps properly [12].Freeland and Hrutfiord (1993) treated old corrugated containers (OCC) with alkali soaking during recycling. They found that the 2% sodium hydroxide at 52 ^{o}C and 14% consistency in four hours treatment conditions were effective for strength improvement of recycled pulps [11].

As mentionedabovebriefly, numerouschemical formulations have shown promising results on recycled pulps, and valuable improving effects reported on recycled pulps. Althoughsomeboroncompundshavebeenutilizedfor Kraft pulpingapproaches on lignocellulosics**[13-15],**there is not much information available onboronbasedtreatmentsonrecycled OCC pulps. Thereby, this study was aimed to to provide more fundamental understanding of the properties of recycled fibers from OCC and to explore selected boron compound treatment (sodium borohydride and boric acid) effects for improvement of the properties of recycled OCC pulps.

MATERIALS AND METHODS

Theadditive and treatment free recycled pulps from old corrugated containers (OCC) were supplied from a commercially operated paperrecycling plant, located in Istanbul, Turkey. It was reported that the knowledge of the stages during the recycling was important for better understanding of cellulose properties and restoring/improving effects [10].Inthisregard, thesameOCC pulpswereused as received, in allrecyclingandtreatmentprocedures.Boricacidandsodiumborohydridehavechosento be treat OCC secondaryOCC fibers during recycling process in order to study restoring effects on selected pulp properties. However, it has been possible to investigate the effect of selected boron compounds more closely on the recycled fibers that have been known since the past and have been subjected to successive drying and wetting processes.Althoughboricacidandsodiumborohydridehavebeenutilized in someindustries, thesehas not yet found a common use in the paper industry. Thepuritylevel of theboroncompounds (boricacidandsodiumborohydride) used is above 95%. The chemicals were supplied directly from the Etibank Borax plant, located in Bandırma, Turkey.Thechemicalcharacteristicsof selectedboroncompoundsare given in Table 1.

Before the secondary OCC pulps were being used for test papermaking, it was first subjected to mixing procedure at room temperature (23 °C) in a laboratory-type standard disintegrator.The laboratory type standard British Sheet Former was used to prepare test papersfromthosepulps**[16].** In order to close control and understand the past and the stages of the recovered fibers, repeatedly five recycling phases were applied on the same sheets. Thereby, 50 sheetswereprepared in firstrecyclingphase, 10 sheetswere reserved and 40 sheetswere repulpedfor second recycling stage. Thisprocedure hadfolloweduptofifthrecyclingstage in similarorder. In each recycling phase, disintegrated/repulped OCC fibers were treated with 5.0% and 10% concentration (w/w) of sodium borohydride and boric acid at least 12 hours (overnight). In thissense, the effects of those chemicals on secondary cellulose fibers were investigated at specific recycling phase.

The test sheets were prepared as120 g/m^2(typicallevelfor OCC manufacturedpapers) accordancewithTappiStandards T-205 **[16].**The test paperswere dried in specificconditionedroomfor 1 day, withoutbeingsubjectedtoanystressortemperatureeffects. Thisprocedure has been applied to all processes within the scope of the study. Hence, it waspossibletoinvestigatetheeffect of certainselectedchemicals on thefibersmorecloselyandcorrectly. Standard paper tests were then applied.Thisinvolvesdetermination of water absorption (Cobb test) was carried out in accordance with the Tappi T-441 standard by weighing 100 ml of waterfor 60 second[17].The Cobb value refers to the percentage of the amount of water absorbed by paper during a certain period of time relative to paper.

The color and opticalproperties of handsheetsweremeasuredaccordingtoTappi T-220[18],ASTM E313[19],and D1925[20], (whitenessandyellowness), Brightness (Tappi T-525)[21]and CIE L*a*b* (1976) strandard methods, respecitvely. The color and optical characteristics of the papers were measured with the X-Rite 938 color spectrophotometer.

In the paper industry, the gloss most frequently measured is specular reflectance. It is the intensity ratio of specularly reflected light to the incident light. Thespecularreflectionoccurs in thesurfacelayer of paperbecauselightthatentersthepaperundergoesmanyreflections. Papergloss at 60° wasmeasuredaccordingto**ASTM D523 [22],**using a GlossgardGlossmeter from (Gardner/Neotec Company, Michigan, USA).

Whilemanycombinationswasutilizedduringrecyclingprocedure of cellulosefibers, somecodenumberandabbreviationswereestablishedthroughoutthestudy given in Figures and Tables. These are: C: Control, Ba: Boric acid; NaB: Sodium borohydride; 5 and 10: chemical concentration %, weight/weight; 1, 2,3,4, and 5: recycling number.

Table 1. The general characteristics of boric acid and sodium borohydride compounds

	Boric acid	**Sodium borohydride**
Chemical formula	H_3BO_3	$NaBH_4$
Composition	56.30% B_2O_3; 43.70% H_2O	60.77% Na; 10.66% H; 28.57% B
Molecular weight	61.84 g/mol	37.83 g/mol
Specific weight	1.435 g/cm^3	1.07 g/cm^3
Melting point	171 ^{0}C	400 ^{0}C
IUPCAC name	Trihydrooxidoboron	Sodium tetrahydridoborate

RESULTS AND DISCUSSIONS

The sheet density (presented as bulk) properties are shown in **Table 2.** In general, the bulk values of the controltest papers were increased at a certain level until the first three recycling processes, and then decreased. A similar trend was also observed on test papers produced from boric acid treated secondary OCC pulps. However, in the treatment with sodium borohydride, only 5.0% concentration and fourth recycle stage ($5NaB_4$) showed a continuous increase. Moreover, the highest bulk valueof 3.41 $cm^3/gr$was found with 10% sodium borohydride treated pulps at the fifth recycle phase($10NaB_5$). Thisvalue is approximately15.98%and24.0%,higherthanthepreviousrecyclingandthecontrolsample at thesamerecyclingstage, respectively. In general, it has been understood the papers produced from sodium borohydridetreated secondary pulps showhigher bulkiness than that of the control and boric acid process in the same recycling phase. In this sense, it could be suggested that sodium borohydridelooks like more effective on density of sheetsthan boric acid. In general, changes in bulk (density) values of paperreproducedfromsecondaryfibersareconsistentwiththeliteraturereports[2, 23,24].

Table 2. Bulk properties of papersmade from recycled OCC pulps

Samples	Bulk (cm^3/gr)	Change (%, from former stage)	Change (%, from control)
C_1	2.80	0.0	0.0
C_2	2.82	0.71	0.0
C_3	2.89	2.48	0.0
C_4	2.82	-2.42	0.0
C_5	2.75	-2.48	0.0
$5NaB_1$	2.72	0.0	-2.86
$5NaB_2$	2.91	6.98	3.19
$5NaB_3$	2.91	0,0	0.71
$5NaB_4$	2.73	-6.18	- 3.19
$5NaB_5$	2.94	7.69	6.91
$10NaB_1$	2.72	0.0	-2.85
$10NaB_2$	2,82	3,68	0.0
$10NaB_3$	2.96	4.97	2.42
$10NaB_4$	2.94	-0.68	4.25
$10NaB_5$	3.41	15.98	24.0
$5Bx_1$	2.80	0.0	0.0
$5Bx_2$	2.91	3.9	0.32
$5Bx_3$	2.54	-12.7	-12.1
$5Bx_4$	2.87	12.9	1.77
$5Bx_5$	2.86	-0.34	4.0

10Bx$_1$	2.88	0.0	2.90
10Bx$_2$	2.91	1.0	3.19
10Bx$_3$	2.82	-3.80	-2.40
10Bx$_4$	2.55	-9.60	-9.57
10Bx$_5$	2.97	16.91	8.0

Table 3 shows comparable water absorption (Cobb) properties of test papers. It can be seen that both boron compounds positively effects on OCC secondary fibers regarding water absorption properties. The highest water absorption value of 135 g/m^2 was observed in 10% boric acid treatment conditions at fifthrecycling stage (10Bx$_5$). However, thisvalue is approximately8.0% and 26.16% higherthantheformerrecycledandcontrolsample at thesamerecyclingphase, respectively. Moreover, the lowest water absorption value of 100 g/m^2 was found in 5.0% sodium borohydride conditions at fifth recycling stage(5NaB$_5$) and this indicates 16.66% and 6.54% lower water absorption properties than the previous and control sample at the same recycling phase, respectively. As a general conclusion from Table 3, it could be saidthat both sodium borohydride and boric acid treatment of secondary OCC pulps have an increase trend regarding water absorption (Cobb) properties.Similarresultshavealreadybeenreportedbynumerousresearchersforothertypepulpsandtreatmentchemicals**[23-25].**

Table3. Water absorption (Cobb) properties of papersmade from recycled OCC pulps

Samples	Water absorption (Cobb) (gr/m^2)	Change (%, from former stage)	Change (%, from control)
C$_1$	126	0.0	0.0
C$_2$	108	-14.28	0.0
C$_3$	108	0.0	0.0
C$_4$	108	0.0	0.0
C$_5$	107	-0.93	0.0
5NaB$_1$	128	0.0	1.59
5NaB$_2$	116	-9.37	7.41
5NaB$_3$	108	-6.89	0.0
5NaB$_4$	120	11.11	11.1
5NaB$_5$	100	-16.66	-6.54
10NaB$_1$	124	0.0	-1.59
10NaB$_2$	104	-16.12	-3.70
10NaB$_3$	116	11.53	7.41
10NaB$_4$	104	-10.34	-3.70
10NaB$_5$	116	11.53	8.41
5Bx$_1$	119	0.0	-5.56
5Bx$_2$	120	0.84	11.1
5Bx$_3$	120	0.0	11.1
5Bx$_4$	123	2.50	13.89
5Bx$_5$	132	7.32	23.36

$10Bx_1$	118	0.0	-6.34
$10Bx_2$	120	1.70	11.1
$10Bx_3$	120	0.0	11.1
$10Bx_4$	125	0.0	17.74
$10Bx_5$	135	8.0	26.16

The basic color values of test papers that produced from control and selected boron treated pulps are prensented in Table 4. It is very difficult to explain all these parameters and correlate to each other while it is also not intent to do in thisstudy. However, it is clearlyseenthatthecolorchanges of test paperstreatedwithbothcompoundshaveverylimitedchangesandmostly in marginallimits (ΔE), in most cases lower than 1.0%. But, it is importanttonotethattheseboroncompoundshavesomelevelpositiveeffects on yellowness values that lowering yellowness values indication less yellow paper.

It can be seen that the sodium borohydride and boric acid has not cause significant changes in both brightness and gloss values. There are even only less than 1.0 degree changes of brightness value depending on the recycling phase (Table 4). However, the paper gloss is a visual impression that is caused when a paper surface is evaluated. The gloss of a paper can be greatly influenced by a number of factors, particularly surface properties (i.e. smothness). The highest gloss value of 5.2 was found in the fifth recycling stage of 5.0% boric acid treated sheets ($5Bx_5$) while the lowest gloss of 3.5 found in 10% boric acid treatment at first recycling phase ($10Bx_1$). It can be understood that the selected chemical substances used for treatemnt OCC secondary fibers do not cause significant changes in the color values of the papers and do not cause important level color reduction.

Table 4. The color properties of papersmade from recycled OCC pulps

	CIE L*,a*, b* properties				**Yellowness Index**		**Bright.**	**Gloss (60^o)**
Samples	**ΔL**	**Δa**	**Δb**	**ΔE**	**ASTM E313**	**ASTM D1925**	**Tappi T525**	**ASTM D2457**
C_1	0	0	0	0	0	0	24.51	3.8
C_2	0.49	0.06	-0.14	0.36	-0.37	-0.43	24.76	4.4
C_3	0.94	0.002	0.006	0.30	-0.21	-0.29	25.52	4.2
C_4	0.71	0.03	0.02	0.28	-0.17	-0.21	25.58	4.3
C_5	1.09	0.014	0.09	0.28	-0.57	-0.76	25.96	4.2
$5NaB_1$	1.09	0.06	0.39	0.52	0.37	-0.32	23.57	3.6
$5NaB_2$	0.69	-0.03	-0.56	0.61	-0.77	-0.87	24.54	4.0
$5NaB_3$	0.32	0.03	-0.27	0.66	-0.37	-0.43	24.31	4.4
$5NaB_4$	0.05	0.25	0.38	0.65	-0.64	-0.52	24.49	4.3
$5NaB_5$	0.23	0.04	0.39	0.49	-0.75	-0.90	24.39	4.6
$10NaB_1$	-1.11	0.08	0.38	0.50	0.33	-0.31	23.73	3.8
$10NaB_2$	-0.83	0.09	-0.61	0.72	-0.81	-0.91	23.83	3.7
$10NaB_3$	0.31	0.02	0.26	0.61	-0.67	-0.82	24.44	4.3
$10NaB_4$	0.23	0.15	0.29	0.62	-0.42	-0.37	24.46	4.0
$10NaB_5$	0.14	0.09	0.33	0.52	-0.60	-0.67	24.45	4.5
$5Bx_1$	0.02	0.20	0.22	0.37	-0.39	-0.72	24.30	4.1

5Bx$_2$	0.83	0.29	0.35	0.75	-0.84	-1.40	24.68	4.3
5Bx$_3$	1.08	0.36	0.11	0.80	-0.46	-1.02	24.33	4.4
5Bx$_4$	1.24	0.24	0.13	0.74	-0.58	-1.02	23.65	4.2
5Bx$_5$	1.21	0.22	0.15	0.76	-0.03	-0.39	24.55	**5.2**
10Bx$_1$	0.69	0,06	0.65	0.66	-0.77	-1,16	24.11	3.5
10Bx$_2$	-0.09	0.24	0.78	0.75	-1.34	-1,07	24.64	3.7
10Bx$_3$	0.14	0.08	0.46	0.66	-0,08	-1,14	24.01	3.8
10Bx$_4$	0.22	0.06	0.45	0.69	0.85	-1,08	24.95	4.1
10Bx$_5$	0.60	0.03	0.40	0.54	-0.74	-0,99	24.61	4.1

Theresultspresented in Table4 has usedtointerpretbothsodiumborohydrideandboricacidcombineeffectswithrecyclingphaseon total colordifferences (ΔE)properties of test papers shown in Figures 1 and 2, respectively. As can be seen the use of sodium borohydride has not clear effects on total color differences but increasing concentration from 5.0% to 10% in lower recycling number negative impact on colors (Figure 1). Although boric acid has only marginal level effects on total color difference, it is important to note that increasing boric acid concentration from 5.0% to 10% and recycling number negative impact on color of test papers (Figure 2).

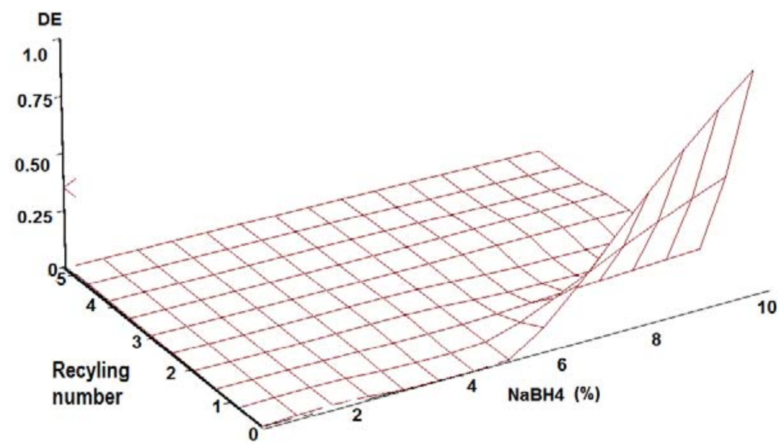

Figure 1. Theeffects of sodiumborohydrideandrecyclingsteps on total colordifference(**ΔE)** of papers.

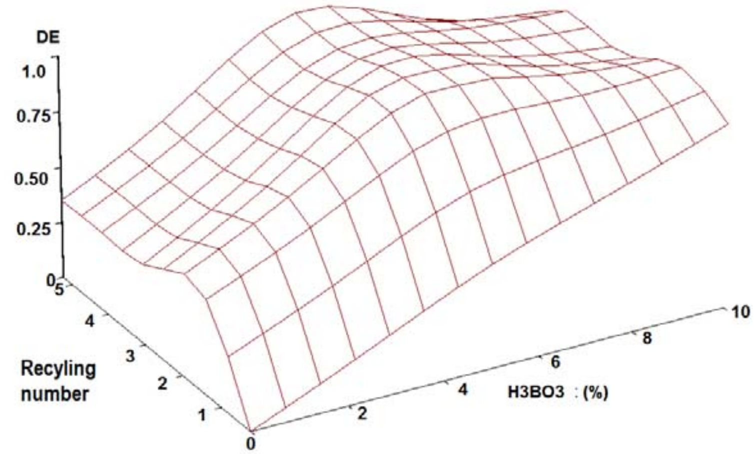

Figure 2. Theeffects of boricacidandrecyclingsteps on total colordifference(ΔE) of papers.

CONCLUSIONS

The old corrugated containersare one of the most recycled paper based material compare to others. This is because of its recovery (recycling) easy and suitable for re-manufacturing of paper and paperboards materials primarily packaging.However, the recycling of these valuable materials has also helps decrease solid waste disposal in landfills. A number of valuable results and suggestions have reported from recycling of post consumer waste papers. But the chemical treatment approaches used in this study are new and generally compatible with the literature data. Moreover, therehas not muchliterature on theeffectsof certainboroncompounds on secondary OCC pulps.

However, the use of boric acid and sodium borohydrideduring recycling of OCC pulps as treatment agent show promising results and even restoring effects on some selected (water absoprsion and optical properties). Thereby, theresultshavepresented in thisstudycould be open an alternativeuseage of thesecompoundsduringrecycling of OCC. Moreover, further studies may be appropriate to elaborate effects of those boron compounds onsecondary fibers in different experimental conditions.

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