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Treatments of Recycled Pulps from Old Corrugated Containers. Part II. The Effects of Boron Compounds on Strength Properties

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Authors' contributions

This work was carried out in collaboration between both authors. Author HTS designed the study, wrote the protocol, managed the literature searches and wrote the first draft of the manuscript. Author MY managed the analyses of the study. Both authors read and approved the final manuscript.

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ABSTRACT

The paper from secondary fibers has generally considered to be used in corrugated cardboard production. For this purpose, Sack Corrugated Test (SCT) and Corrugated Medium Tests were used to determine the strength resistance behaviors. The highest CMT value of 73.5 N was found with first recycling stage of control samples. For boron treated pulps, the highest CMT of 63.3 N was found at 10% boric acid treatment at second recycling phase followed by 5.0% boric acid treatment at second recycling phase, respectively. However, some level improvement of SCT properties was observed at certain level both boric acid and sodium borohydride treatment conditions. the highest improvements of SCT of test papers was found with 5.0% boric acid treatment at forth recycling phase that show approximately 39.74% improvement compared to control. Moreover, at the fifth recycled stage, quite high burst strength values observed with both selected boron treatment conditions that approximately 32.31% and 35.94% higher burst strengths at 5.0% level while 20.32% and 14.06% higher burst strengths at 10% boric acid and sodium borohydride level

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compare to control sample at similar recycling phase. The more less similar trend was also observed for tensile strength properties of test papers. The highest tensile strength (index) of 19.74 Nm/g and tensile stiffness value of 386 kN/m was observed at second recycling phase with boric acid. For tensile energy absorption (TEA) properties, only 10% sodium borohydride treated test papers showed higher TEA of 23.25 j/m^2 compared to counterpart control samples (C_2: 20.60 j/m^2).

Keywords: Old corrugated container; recycling, boron compounds; tensile strength; burst strength; corrugated medium test.

1. INTRODUCTION

The multi-stage paper production stages affect the structure of cellulose by both chemically and physically [1]. To manufacture paper products from recovered cellulosic fibers (secondary fibers/pulps), the secondary pulp needs to have intrinsic strength and some certain properties. However, it was noted that some of the fillers have removed during recycling, which indicates that papermaking from secondary pulps requires higher fillers [2]. Moreover, the cellulose fiber undergoes mechanical and drying cycles during papermaking and causing a very complex phenomenon and has not fully explained yet. These changes have usually called *hornification* that irreversible changes of hydrogen bonding potential and hydrophilic nature of cellulose fibers [3-7]. In addition, the removing of hemicellulose and lignin from the cell wall during recycling also causes the collapse and negative impact on cellulose structure. In hornificated fibers, the amorphous region has typically reduced to some extent resulting increasing crystalline index with lowering re-wetting propeties of fibers [7-11].

Since environmental concern and protection of natural forestslands for papermaking industry, the recycling of post-consumer paper products has become an important issue in worldwide. Hence many technologies and alternative approaches have become established regarding waste paper recycling.

A typical paper sheet is a composite material that contains cellulosic fibers, air, fillers and some extraneous materials. However, fiber-fiber bonding is closely associated with fibers contact areas and important parameter for paper strengths [12]. Certain chemicals have been reported to be promote fibre bonding and improve paper properties some level [3,13-16]. It was proposed by Wistara and Young (1999) that the microstructure of cellulose must be modified to establishing further swelling capacity. Moreover, hemicelluloses have also important influences in regulating the physical properties of the pulps during recycling [15]. It was reported that the cellulose fabrics treated with banana pseudo stem sap (BPS) an plant extract, show stable natural color, and there was no significant degradation in mechanical strengths with imparting flame retardancy to cellulose substrate [16]. Basak et al., utilized green coconut shell extract (GCSE), obtained by extraction of green coconut shell and employed along with boric acid (BA) as a fire retardant agent for cellulosic paper. The GCSE and 2% BA application were reported to be enhancing flame resisting property to cellulose paper [17].

Although some research conducted for pulping of lignocellulosics with boron compunds, and valuable restoring effects on pulp properties [18-22], there has not much information available in literature regarding certain boron compounds treatments of secondary pulps and their effects on paper properties. A systematic approach have carried out with boric acid and sodium borohydride on recycled old corrugated containers (OCC) substrate to determine clear effects on recycling approach and chosen methods. In the first part of this study, *'Treatments of Recycled Pulps from Old Corrugated Containers. Part I. The Effects of Boron Compounds on Optical and Physical Properties'* has already *submitted for publication.* In the second part of this study, it is aimed to study for providing more fundamental understanding of the strength development of recycled fibres from old corrugated container (OCC) fibers.

2. MATERIALS AND METHODS

The additive and treatment free recycled pulps from old corrugated containers were supplied from a commercially operated paper recycling plant, located in Istanbul, Turkey. The purity level of the boron compounds (boric acid and sodium borohydride) used is above 95%. The chemicals were supplied directly from the Etibank Borax plant, located in Bandırma, Turkey. The test papers were prepared as 120 g/m^2 (typical level for OCC manufactured papers) accordance with Tappi Standards (T-205) [23]. The detailed information on boron compounds, experimental recycling procedures for treatment of OCC substrate and related similar informations have already given in first part of this study.

The standard paper strength tests were applied. These involves determination of the mechanical properties of handsheets were measured according to Tappi T-494 [24] and burst strengths [25]. Sack Crushing Strength Test or Short Compression Test (SCT) that is is indicates internal compression resistance of paper fibres and suitable for fluting in the middle layer of the cardboards, was applied on sheets accordance with ISO 9895 standard [26]. The SCT properties of papers are expressed in Kilonewtons/Meter (kN/m).The Corrugating Medium Test (CMT) was also conducted on hand sheets followed ISO 7263 standard [27]. The CMT determines the flat crush resistance of corrugating papers and made on laboratory corrugated samples for describing the usability for fluting. CMT is a way of estimating the crush resistance of corrugated board manufactured with those papers. The CMT is expressed in Newtons (N). Both SCT and CMT tests have used after forming corrugated paper forms, and usually applied on corrugated papers alternatively to each other.

While many combinations were utilized during recycling procedure of cellulose fibers, some code number and abbreviations were established throughout the study given in Figures and Tables. These are: C: Control, Bx: Boric acid; NaB: Sodium borohydride; 5 and 10: chemical concentration %, weight/weight; 1, 2,3,4, and 5: recycling number.

3. RESULTS AND DISCUSSION

The burst strength values of the test papers produced from the control and treated pulps are given comparatively in Table 1. It has realized that the burst strengths of control papers have increased in the first two recycling steps. Then, it has showed a downward trend in further recycling operations. The similar results have also been observed with sodium borohydride and boric acid treated pulps.

However, in general, the burst strength values of sodium borohydride and boric acid treated pulps show about 3.22% to 20.43% lower than the control samples up to fourth recycling steps. Interestingly, at the fifth recycled phase, quite high burst strength values observed that approximately 32.31% and 35.94% higher at 5.0% concentration while 20.32% and 14.06% higher burst strengths at 10% concentration in comparison to control sample at similar recycling phase. It is important to note that selected boron compounds used in this study exhibit a more moderate reduction on burst strength, even though they may only limited improvements in recycling phases.

Figs. 1 and 2 show the effects of boron compounds concentration in recycling stages on burst strength properties of hand sheets. It has been observed that the increasing sodium borohydride concentration at higher recycling phase has no positive effects while at lower recycling number (up to two) and sodium borohydride concentration shown to improving burst strengths of sheets (Fig. 3). Like sodium borohydride treatments, lower recycling phase (up to two) but in both level boric acid concentration have increasing effects on burst strengths of sheets (Fig. 4). iIncreasing recycling phase beyond second recycling phase have not effective for improving burst strengths of papers.

In Table 2 the tensile strengths properties of the test papers are given comparatively. In general, the tensile properties (index) of control samples did not change much and even decreased only by 1.20% to 5.79%, continuously recycling procedure. It is important to note that no any improvements was observed with sodium borohydride treated pulps regardsless of concentration and recycling phase, except 10% treatment conditions at second recycling stage ($10NaB_2$) that shows only 3.23% improvement in comparison to control samples.

For boric acid treatments, except in 5.0% conditions at first recycling stage ($5Bx_1$), 2.69 to 8.34% improvements of tensile strengths were observed compare to counterpart control samples. The highest tensile index of 19.74 Nm/g was observed at second recycling stage ($5Bx_2$).

Stretch is usually reported percentage of elongation. As seen in Table 2, marginally changes were observed regarding stretchs of papers. However, tensile stiffness is the ratio of tensile force per unit width to tensile strain within the elastic region of the tensile-strain relations. The highest tensile stiffness value of 386 kN/m was observed with 5.0% boric acid treatment at fifth recycling phase that is the only higher value for boron treated pulps regardless of recycling phase, than counterpart control samples. Tensile energy absorption (TEA) is the work done when a specimen is stressed to rupture in tension under prescribed conditions. It is expressed as energy per unit area (test span × width) of test specimen. For sodium borohydride treatments of secondary pulps, only 10% treated pulps at second recycling phase ($10NaB_2$) show higher TEA of 23.25 J/m^2 compared to counterpart control samples (C_2: 20.60 J/m^2). It is important to note that boric acid seems to be effective only at 5.0% concentration phase (except first recycling stage).

Table 1. Burst strength properties of papers made from recycled OCC pulps

Sample	Burst strength (kPa)	Burst index (kPa m^2/g)	Change (%, from former treatment)	Change (%, from control)
C_1	119	0.95	0.0	0.0
C_2	118	1.07	8.42	0.0
C_3	98	0.88	-17.75	0.0
C_4	102	0.93	5.68	0.0
C_5	70	0.64	-31.18	0.0
$5NaB_1$	95	0.86	0.0	-9.47
$5NaB_2$	115	0.92	6.97	-14.10
$5NaB_3$	92	0.84	-8.69	-4.54
$5NaB_4$	99	0.90	0.71	-3.22
$5NaB_5$	87	0.85	-5.56	**32.31**
$10NaB_1$	101	0.81	0.0	-14.73
$10NaB_2$	98	0.89	9.87	-16.82
$10NaB_3$	84	0.78	-12.36	-11.36
$10NaB_4$	85	0.83	6.41	-10.80
$10NaB_5$	68	0.77	-16.87	20.32
$5Bx_1$	104	0.83	0,.0	-12.63
$5Bx_2$	119	1.08	30.12	0.93
$5Bx_3$	93	0.82	-24.07	-6.81
$5Bx_4$	93	0.86	4.87	-7.53
$5Bx_5$	104	0.87	1.16	35.94
$10Bx_1$	114	0.91	0.0	-4.21
$10Bx_2$	110	1.0	9.89	-5.61
$10Bx_3$	88	0.80	-20.0	-9.09
$10Bx_4$	81	0.74	-7.50	-20.43
$10Bx_5$	66	0.73	-1.35	14.06

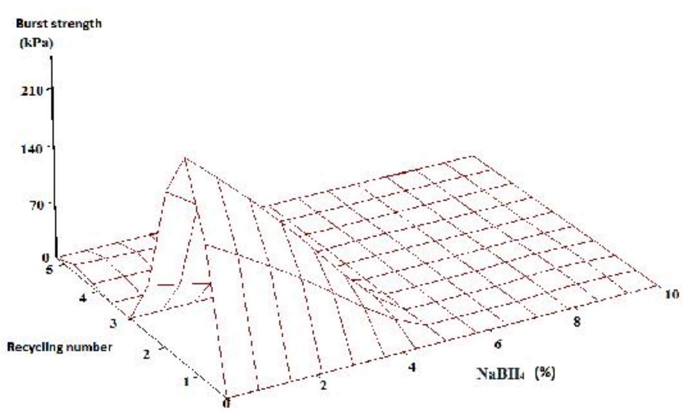

Fig. 1. The effects of sodium borohydride concentration and recycling phase on burst strengths of papers

From the results observed in Table 2, it can be summarized that treatment of OCC secondary fibers with both boron compounds at 5.0% treatment levels have some restoring/improving effects on the tensile strength values at certain treatment phases.

Figs. 3 and 4 show the combined effects of sodium borohydride and boric acid concentration during recycling phases on tensile strength properties of test papers. It has been observed that the increasing sodium borohydride concentration at low recycling phase marginally improving effects (Fig. 3). In contrast to sodium borohydride, low level of boric acid concentration and higher recycling phase positively affects tensile strengths of sheets (Fig. 4). In this sense, increasing boric acid contcentration to 10% up to third recycling phase not effective for improving tensile strengths of papers.

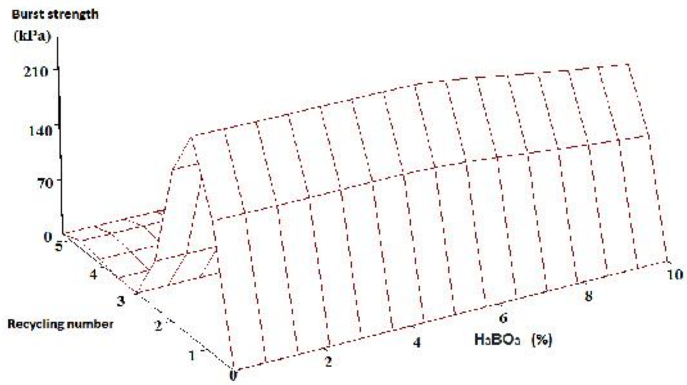

Fig. 2. The effects of boric acid concentration and recycling phase on burst strengths of papers

Table 2. Tensile strength properties of papers made from recycled OCC pulps

Sample	Tensile strength (kN/m)	Stretch (%)	TEA (J/m^2)	Tensile stiffness (kN/m)	Tensile index (Nm/g)
C_1	2.40	1.69	31.20	356	19.34
C_2	2.15	1.34	20.60	341	18.22
C_3	2.09	1.28	19.15	313	18.0
C_4	2.08	1.27	16.10	255	18.26
C_5	2.24	1.21	18.15	328	18.98
$5NaB_1$	2.02	1.88	26.75	269	16.10
$5NaB_2$	1.85	1.52	20.40	273	16.67
$5NaB_3$	1.93	1.25	17.05	272	17.79
$5NaB_4$	1.87	1.27	16.10	254	17.32
$5NaB_5$	2.02	1.29	17.85	291	18.53
$10NaB_1$	1.77	1.96	25.0	212	14.71
$10NaB_2$	2.05	1.59	23.25	274	18.81
$10NaB_3$	1.72	1.20	14.10	259	17.73
$10NaB_4$	1.80	1.80	16.20	257	17.39
$10NaB_5$	1.54	0.95	10.33	266	17.50
$5Bx_1$	1.93	1.72	23.25	254	16.69
$5Bx_2$	2.23	1.45	22.90	302	19.74
$5Bx_3$	2.13	1.32	19.50	290	18.85
$5Bx_4$	2.16	1.29	19.80	296	18.94
$5Bx_5$	2.30	1.14	19.15	386	19.49
$10Bx_1$	1.96	1.71	24.0	253	15.68
$10Bx_2$	1.93	1.09	14.83	289	17.31
$10Bx_3$	1.97	1.42	19.25	267	18.41
$10Bx_4$	1.74	1.20	14.20	253	16.57
$10Bx_5$	1.42	1.10	10.71	228	13.40

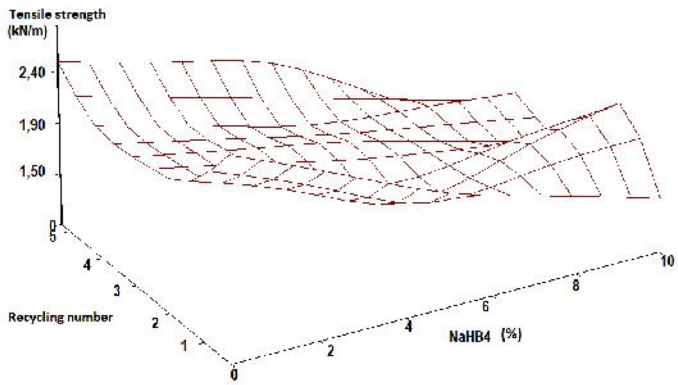

Fig. 3. The effects of sodium borohydride concentration and recycling phase on tensile strengths of papers

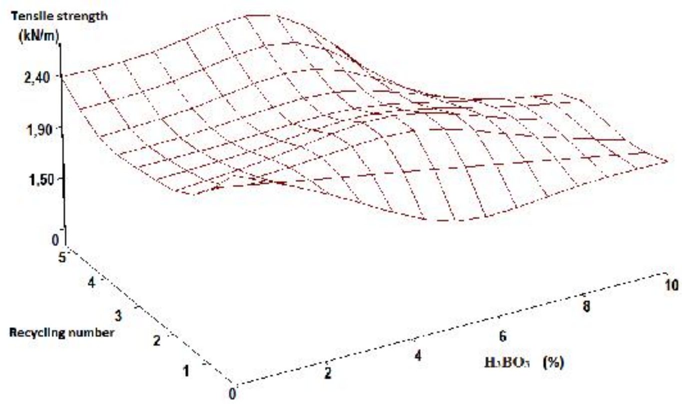

Fig. 4. The effects of boric acid concentration and recycling phase on tensile strengths of papers

The Corrugate Medium Test (CMT) values of the test papers are given in Table 3. It can be seen that there is not certain restoring trend realized for the CMT values of test papers. It seems to selected boron compounds have not positively affected the CMT of papers. The highest CMT value of 73.5 N was found after first recycling stage of control samples. However, for boron treated pulps, the highest CMT of 63.3 N was found at 10% boric acid treatment at second recycling phase ($10Bx_2$) followed by 5.0% boric acid treatment at second recycling phase ($5Bx_2$), respectively.

Figs. 5 and 6 show the effects of boron compounds of sodium borohydride and boric acid in recycling phases on CMT properties of test papers. It has been observed that the increasing sodium borohydride concentration does not influence on CMT values while increasing reycling number negatively affects the test papers. Interestingly, more less similar trend was also observed in case of boric acid treatment conditions as seen in Fig. 6.

The paper from secondary fibers has generally considered to be used in corrugated cardboard production. For this purpose, Sack Corrugated Test (SCT) is used to determine the surface crush strength resistance behaviors. In this test, the content of paper is more sensitive than fiber content as compared to conventional testing methods. In Table 4, the SCT values of the test papers produced from the treated secondary fibers with the control and boron compounds are given comparatively. As seen in Table 4, the SCT properties of the (control) papers showed a steady decline as the recycling stage increased. It is very complicated to interpret the data presented in Table 4. However, some level improvement of SCT properties was observed at certain level of samples treated by both boric acid and sodium borohydride. However, the highest SCT value of 1.18 kN/m was found for control sample (C_1). The highest improvement of SCT of test papers under treatment conditions with 5.0% boric acid at forth recycling phase ($5Bx_4$) that shows approx. 39.74% improvement as compared to control samples (C_4: 0.78 kN/m vs $5Bx_4$: 1.09 kN/m), followed 16.44% improvement by fifth recycling phase at same boric acid concentration.

Table 3. Corrugated Medium (CMT) strength properties of papers made from recycled OCC pulps

Sample	CMT (N)	Change (%, from former treatment)	Change (%, from control)
C_1	73.5	0.0	0.0
C_2	60.7	-17.41	0.0
C_3	50.0	-17.62	0.0
C_4	46.0	-8.0	0.0
C_5	45.7	-0.06	0.0
$5NaB_1$	69.3	0.0	-5.71
$5NaB_2$	54.3	-21.64	-10.54
$5NaB_3$	46.7	-13.99	-6.60
$5NaB_4$	43.7	-6.2	-5.00
$5NaB_5$	39.0	-10.76	-14.66
$10NaB_1$	61.7	0.0	-16.05
$10NaB_2$	59.0	-4.38	-2.80
$10NaB_3$	40.1	-3.03	-19.98
$10NaB_4$	37.0	-7.73	-19.56
$10NaB_5$	29.7	-1.72	-35.01
$5Bx_1$	63.3	0.0	-13.54
$5Bx_2$	**62.3**	-1.58	2.63
$5Bx_3$	43.3	-30.49	-13.40
$5Bx_4$	41.7	-12.70	-7.17
$5Bx_5$	36.0	-21.21	-21.22
$10Bx_1$	60.7	0.0	-17.41
$10Bx_2$	63.3	5.43	4.28
$10Bx_3$	43.3	-31.59	-13.40
$10Bx_4$	39.0	-9.90	-15.21
$10Bx_5$	29.7	-23.84	-35.01

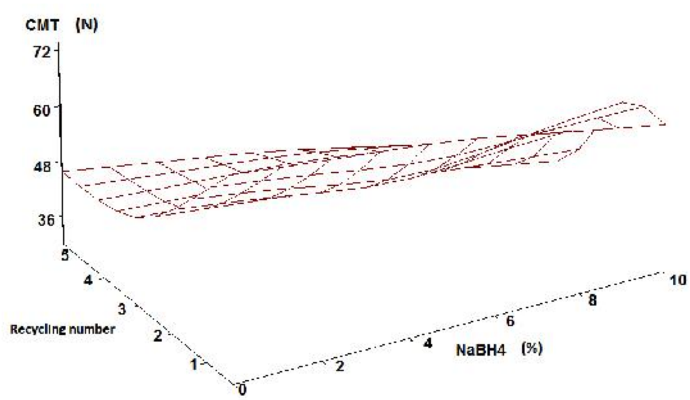

Fig. 5. The effects of sodium borohydride concentration and recycling phase on CMT properties of papers

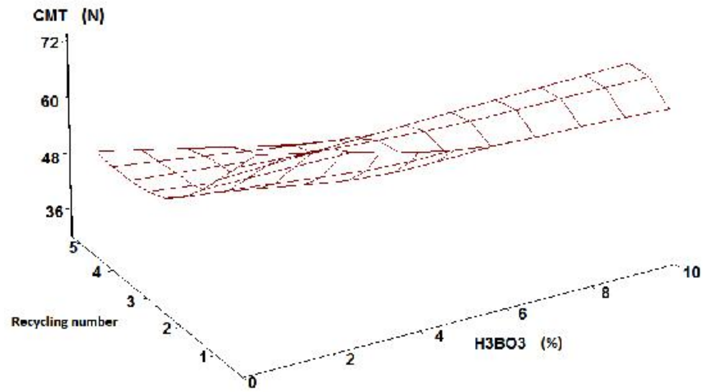

Fig. 6. The effects of boric acid concentration and recycling phase on CMT properties of papers

Table 4. SCT strength properties of papers made from recycled OCC pulps

Treatment	SCT (kN/m)	Change (%, from former treatment)	Change (%, from control)
C_1	1.18	0.0	0.0
C_2	1.16	-1.72	0.0
C_3	1.09	-7.62	0.0
C_4	0.78	-28.44	0.0
C_5	0.73	-0.64	0.0
$5NaB_1$	0.96	0,0	-17.24
$5NaB_2$	0.88	-9.38	-26.27
$5NaB_3$	0.87	-1.14	-19.27
$5NaB_4$	0.78	-11.36	0.0
$5NaB_5$	0.92	17.94	8.00
$10NaB_1$	0.90	0.0	-22.41
$10NaB_2$	1.09	21.11	-7.63
$10NaB_3$	0.92	-15.59	-15.59
$10NaB_4$	0.84	-8.69	7.69
$10NaB_5$	0.67	-20.24	-8.21
$5Bx_1$	0.99	0.0	-14.65
$5Bx_2$	1.15	16.16	-2.54
$5Bx_3$	1.0	-13.04	-8.26
$5Bx_4$	1.09	8.26	39.74
$5Bx_5$	0.85	-22.02	16.44
$10Bx_1$	0.98	0.0	-15.51
$10Bx_2$	1.13	15.31	-4.23
$10Bx_3$	0.92	-18.58	-15.59
$10Bx_4$	0.82	-10.87	-5.13
$10Bx_5$	0.66	-19.51	-9.59

The results given in Table 4 were used to interpret selected boron compounds and recycling phase effects on SCT properties of tested papers. Hence, sodium borohydride and boric acid effects during recycling stages effects on SCT properties presented in Figs. 7 and 8, respectively. It can be seen that middle level of recycling (up to third) with 10% sodium borohydride has some improving effects on SCT properties (Fig. 7). However, treatment of secondary OCC fibers with boric acid was found to have the only positive effect on the SCT properties at low concentration (5.0%) and at middle level recycling stages (up to third) (Fig. 8).

In general, it has been observed that the increase in recycle number and selected boron content concentrations have usually negative

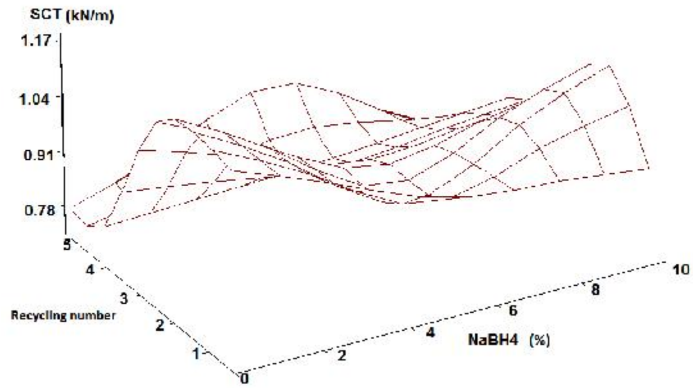

Fig. 7. The effects of sodium borohydride concentration and recycling phase on SCT properties of papers

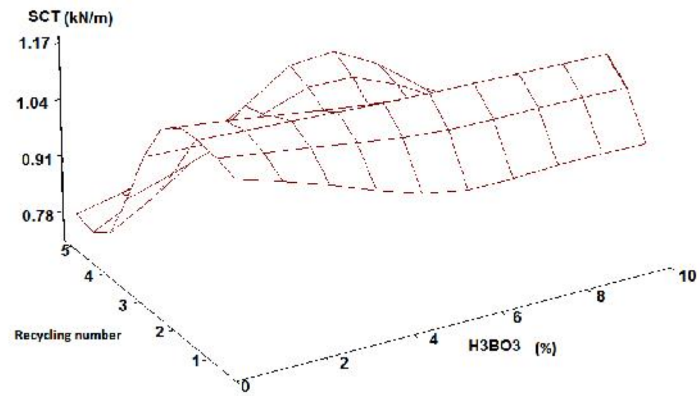

Fig. 8. The effects of boric acid concentration and recycling phase on SCT properties of papers

impact on the SCT properties of the test papers, but the SCT value changes were found to be within marginal levels for certain treatment conditions (see in Table 4).

Wistara et al. (1999) reported that the recycling affects lowering surface energy of cellulosic fibers. This hypothesis has been suggested that the disruption of hemicelluloses may occur during recycling of cellulose. They have proposed that some compounds could be capable oxidizing fiber surfaces resulting increasing carboxylic and OH groups on the surface of the fibers during recycling. These clearly affect substitution of -OH groups and resulting further swelling and, improve physical properties of sheets [15]. In our study, there has only marginal improvements of paper strengths was observed while some properties have been found to be restore at certain boron compounds treatment conditions.

4. CONCLUSIONS

The corrugated container manufaturing is an important sub parts of papermaking industry. This is because of wide utilization of these products in packaging and transportation needs other consumer products. Thereby, the recycling of these products has important issue and to modify on similar products that they usually re-manufactured from those recycled fibers. The selected boron treatments of the recovered secondary OCC pulps are aimed to improve some strength properties of sheets made. Although the use of boric acid and sodium borohydride during recycling of OCC pulps as treatment agents shows variables and limited restoring/improving results on some selected strength properties, the results have found in this study might be a basement for further studies.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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