Effect of chitosan and cationic starch as wet-end additives to enhance the strength properties of paperboard using OCC recycled pulp



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Abstract :

Paper and paperboard are widely used in packaging for various products and applications. The use of biopolymers in papermaking and packaging industry provides a sustainable alternate as the consumption is expected to grow in foreseeable future. During papermaking, other chemicals or polymers such as wet-end additives like fillers, retention aids, strength additives (starch, carboxymethyl cellulose, polyvinyl alcohol, etc.), defoamers, flocculating agents, etc. are required along with cellulosic fibers. To increase the strength of paper native starch and modified starch like cationic starch are chiefly used as strength additives. In the present study, two different types of pulp furnishes of old corrugated containers (OCC) were used for paperboard making using cationic starch and chitosan, a new biopolymer as wet-end additives to enhance the strength of paperboard. The efficacy of both strength additives was compared by evaluating the effect of different doses of each on strength properties. With chitosan at a dose level of 1 kg/t at wet-end with OCC-1, the breaking length of paperboard was almost comparable whereas with 1.5 kg/t dose, the breaking length, tear index and burst index were found comparable to paperboard made using 20 kg/t of cationic starch at wet-end. Similar results were found with OCC-2 also.

Keywords: Cationic starch, Chitosan, Old corrugated containers, Strength properties and Papermaking

1. Introduction

Paper and paperboard plays a wide role in packaging industry. Packaging is a combination of art and science to protect and enhance the life or shelf life of product which can be edible or non edible, which can be in any form solid or liquid or gas. A paper used for packaging purpose must have high tensile strength, burst strength, tear strength, stiffness and barrier for gases, moisture, odor, fat, etc. Packaging need properties of packaging material according to the nature/ type of material/ object to be packed in, such as for food packaging barrier properties become more important while for solid material the main focus is on strength properties.

Most common renewable packaging materials like paper, paperboard and corrugated boxes are cellulose based (1-3). Cellulose is a renewable, recyclable and biodegradable polymer therefore it is widely used to make paperboard which acts as a basic raw material for converting industries to make carton boxes and corrugated containers. In paper and paperboard the cellulose fibers are held together by hydrogen bonds. The strength of paperboard depends on the number of hydrogen bonds between the cellulose fibers (4-7).

During paperboard making various chemicals are added to pulp slurry which not only impart different properties to paperboard but also improve the machine performance. All these chemicals are not environmental friendly because most of them are petroleum based therefore a biopolymer as an alternate can turn into a boost for our environment. A strength additive for paper and paperboard should be soluble in water, substantive to and compatible with cellulose surface and it should contain a functional group capable of ionic or covalent bonding with the fibers (4, 7-8).

Starch mainly consists of varying proportions of two homo polysaccharides i.e. amylose (linear) having 1, 4-α-D-glucopyranosyl units and amylopectin (branched) having an additional 1, 6-α-D-glucopyranosyl linked branching. This linked branching altogether imparts unique properties of gelatinization and retrogradation to the polymer whereas chitosan consists only of linear chain and due to presence of amino group at each glucose unit it has strong cationic character than cationic starch (9-11).

When degree of deacetylation of chitin reaches about 50% then chitosan is formed (depending on the origin of the polymer) which has high positive charge, low toxic, biodegradable, biocompatible, antibacterial and antifungal by nature. It is a high molecular mass linear carbohydrate composed of β-1,4-linked 2-amino-2-deoxy-D-glucose units (10 and 12-13). Chitosan has a molecular structure that contains hydroxyl and amine group (1-2 and 7). The presence of primary amines at the C-2 position of chitosan is a distinctive property because it increases ability to react with cellulose and also imparts different functional properties to chitosan (8 and 14-15). Solubility of chitosan is very much influenced by its degree of deacetylation and molecular weight of chitosan. Chitosan is not soluble in water until its pH is <6.2 (16). Chitosan effectively neutralizes the anionic charge of the pulp slurry which improves the retention on pulp, drainage time and simultaneously increases the strength of paper by increasing the number of bonds between cellulose fibers (17).

Most of the research has been done on wet-end efficacy of chitosan on different pulps (1-3, 7-8, 10, 12 and 14) but its efficacy in making paperboard with OCC pulp has not been observed yet. Herein, the focus is to explore the potential of chitosan in paperboard making as strength additive and compare the efficacy with traditionally used strength additive i.e. cationic starch (CS) by analyzing the pulp slurry and evaluating various paperboard properties.

2. Materials and Methods

2.1. Materials

Two types of old corrugated containers pulps (OCC-1 and OCC-2) were prepared in lab by recycling. Wet-end chemicals used were: Alkyl ketene dimer (AKD) collected from Sood Resins and Polymers, Himachal Pradesh; Cationic starch (CS) of 0.020-0.025 degree of substitution procured from Bharat starch Industries Limited, Yamuna Nagar. Low molecular weight cationic polyamine fixing agent (CFA) and Percol-47 (retention aid, a medium to high molecular weight cationic polyacrylamide (CPAM) flocculant) were collected from BASF Chemicals Ltd. Chitosan flakes were procured from a chemical manufacturer in South India. All chemicals used were of high purity and analytical grade.

2.2. Analytical techniques

2.2.1. Characterization of pulp and wet-end chemicals

Moisture content of pulp was determined as per TAPPI Test Method T 210 cm-86. For determination of charge demand, the pulp slurry was filtered through 200 micrometer screen and 10 ml of the filtrate was taken as the sample. The charge demand of pulp slurry was measured on Mutek PCD 03 pH particle charge detector; here the pulp slurry was titrated with cationic/ anionic polymer to neutralize the charge.

The initial Schopper Riegler (°SR) as per TAPPI T 227 om-09/ Freeness in term of CSF (ml) for OCC-1 and OCC-2 were 22°SR/ 560 ml and 20.5°SR / 585 ml, respectively. Drainage time of pulp slurry was done as per TAPPI T 221 cm-09 (modified Schopper Riegler tester), which is measured as the time required to drain 800 ml of water from pulp slurry. Ash of pulp and paperboard was done as per T 211 om-02. Mean length (mm) and mean width (μm) was measured by L&W fiber tester. Water retention value of pulp was measured as per TAPPI T 236 um. Bauer McNett fiber classification of pulp was done as per TAPPI T 233. Particle size distribution was done by Horiba particle size analyzer based on laser scattering technique.

2.2.2. Characterization of chitosan and CS

Moisture content of chitosan was done by putting sample in oven at 105°C for 24 h and total ash content of chitosan was evaluated in muffle furnace at 650°C for 3 h (12). Moisture content and total ash content of CS were determined by IS: 4706 (part II). Viscosity of CS and chitosan was measured using Brookfield viscometer at 100 rpm using spindle number 1.

2.2.3. Preparation of wet-end chemicals

CS of 1% solids (w/v) was cooked at 90±2°C for 30 min with continuous stirring using an agitator. AKD emulsion was diluted to 1% solids by addition of distilled water before addition to pulp stock. CFA solution of 0.1% concentration was prepared in distilled water. 1 g of the liquid CFA was weighed and the volume was made up to 1 L using distilled water. CPAM solution of 0.1% (w/v) was prepared in distilled water by gradual addition of the granules in lukewarm water (40-45°C) with continuous mild stirring of about 400 rpm for 30 min. 1% Chitosan solution was prepared in 1% acetic acid at room temperature by stirring for 4 h using magnetic stirrer. Different chemicals and additives were added to the pulp slurry in the following sequence with continuous stirring: CFA-200 g/t, strength aid (CS or chitosan) variable doses, AKD-1 kg/t, filtered water was used to make pulp slurry of 0.3-0.4% consistency, finally retention aid 200 g/t was added to the pulp slurry. No wet-end chemicals were added in the control set experiments.

2.2.4. Evaluation of different doses of CS and chitosan as strength additives

Strength additives are essential wet-end additives during papermaking which enhance the strength properties by increasing the number of hydrogen bonds between cellulosic fibers. Two different polymers namely CS and chitosan were evaluated at different dosages for their efficacy to increase the strength properties of paperboard. CS was investigated at dose levels of 10 kg/t, 20 kg/t, 25 kg/t, 30 kg/t, 35 kg/t, and 40 kg/t with OCC-1 coded as A, B, C, D, E and F, respectively whereas with OCC-2 the dose levels of investigation were 20 kg/t, 30 kg/t and 40 kg/t coded as G, H and I, respectively. Chitosan with OCC-1 was evaluated at different dose levels of 0.30 kg/t, 0.50 kg/t, 0.75 kg/t, 1.0 kg/t and 1.5 kg/t marked as J, K, L, M and N, respectively whereas with OCC-2 it was evaluated at dose level of 1.0 kg/t and 1.5 kg/t marked as O and P, respectively. Control set of OCC-1 and OCC-2 was marked as C-1 and C-2, respectively. GSM of all sets was found in the range 205±5 and bulk was in the range 1.57±0.05. 12 different sets of paperboard handsheets were prepared using OCC-1 and 6 different sets of paperboard handsheets were prepared using OCC-2 pulp. Paperboard handsheets were prepared on laboratory handsheet former as per TAPPI T 272 sp-97. Sheet pressing and drying was done according to TAPPI T 218 sp-02. The handsheets were conditioned at 27±2°C and 65±5% relative humidity for at least 24 h as per ISO: 187.

2.2.5. Paperboard properties

The physical strength properties and surface characteristics of paperboard were determined as per IS standards that include: Thickness (IS:1060 (Part I)), burst index (IS:1060 (Part I)), breaking length (IS:1060 (Part I)), tear index (IS:1060 (Part I)), $Cobb_{60}$ (IS:1060 Part I) and wax pick number (IS:1060 Part III). All the experiments were performed in triplicate and the average value has been reported here.

3. Results and Discussion

Present study was carried out to encounter the effects of CS and chitosan at different varying dose levels. The CS dose level in the range of 10 kg/t to 40 kg/t and chitosan dose level in the range of 0.30 kg/t to 1.5 kg/t was used as strength additive in wet-end of paperboard making. Paperboard using CS and chitosan as wet-end strength additive showed significant improvement in surface properties and physical properties.

3.1. Characterization of pulp and wet-end chemicals

Steaming potential (mV), charge demand (μeq/L) and pH of OCC-1 were -230, 34.8 and 7.90, respectively whereas for OCC-2 they were -200, 32.3 and 7.95, respectively. The time for 800 ml of slurry to pass though the nozzle of modified Schopper Riegler instrument was reported as drainage time. Drainage time and water retention value of OCC-1 were 18 s and 155%, respectively whereas these values for OCC-2 were 19 s and 171%, respectively. Higher water retention value can be correlated to poor drainage as found in the present study. Mean length (mm) and mean width (μm) of OCC-1 were 0.762 and 19.9, respectively whereas for OCC-2 the same were 1.120 and 24.8, respectively as shown in table 1. Fiber classifier data showed that fibers retained over 28 mesh screen (+28 fraction) and fines passing through 200 mesh screen (-200 fraction) were found more in OCC-2 pulp as shown in table 2.

Viscosity of chitosan and CS of 1% solution at 25°C was observed to be 190 cP and 25 cP, respectively. The pH, ash, moisture and charge demand (μeq/g) of chitosan were 4.20, 2.6%, 13% and 700 (anionic), respectively whereas for starch all such properties were found to be 6.2, 1.2%, 10% and 40.3 (anionic), respectively as shown in table 3. Charge demand/ pH of CFA, CPAM and AKD was 3170 (anionic)/ 6.2, 1527 (anionic)/ 4.5 and 266 (anionic)/ 3.9, respectively as shown in table 4. Particle size distribution of AKD showed that mean size of particle, median size of particle and % of particles < 2μm was 0.35, 0.84 and 83.4%, respectively as shown in table 5.

Table 1: Characterization of pulp

	Pulp	
Properties	**OCC-1**	**OCC-2**
°SR	22	20.5
CSF	560	585
Colloidal charge (μeq/L)	34.8	32.3
Steaming potential, mV	-230	-200
pH	7.90	7.95
Drainage time for 800 ml, s	18	19
Mean length of fiber, mm	0.762	1.120
Mean width, μm	19.9	24.8
Water retention value , %	155	171
Ash, %	7.52	8.02

Table 2: Classification of pulp by Bauer McNett fiber classifier

Mesh Size	OCC-1 (Weight %)	OCC-2 (Weight %)
+ 28	46.2	52.6
- 28, + 48	19.6	14.6
- 48, + 100	14.5	13.6
-100, + 200	7.9	2.1
-200	11.8	17.1

Table 3: Characterization of chitosan and cationic starch

Parameters	Chitosan 1% solution in 1% acetic acid	Cationic starch 1% in distilled water
Viscosity, cP @ 25° C	190	25
pH	4.20	6.2
Ash, %	2.6	1.2
Moisture, %	13	10
Charge demand , μeq/g	700 (Anionic)	40.3 (Anionic)

Table 4: Evaluation of wet-end chemicals

Wet-end chemicals	Colloidal charge demand , μeq/g	pH
CFA	3170 (Anionic)	6.2
CPAM	1527 (Anionic)	4.5
AKD	266 (Anionic)	3.9

Table 5: Particle size distribution of AKD

Particle size distribution, μm	Cumulative % on Diameter
10	99.9
5	97.0
3	92.0
2	88.2
1	***83.4***
0.5	73.2
Median size	0.35
Mean size	0.84

3.2. Step by step analysis of charge demand of pulp (OCC-1 and OCC-2) after addition of each wet-end chemical

With OCC-1 the initial charge demand (μeq/L) was 34.8, while after addition of CFA the charge was reduced to 33.4. The charge demand was further reduced when the dose of CS after CFA addition was increased from 20 kg/t to 40 kg/t. Also, after addition of AKD and CPAM the charge demand further reduced in B, D and F and the final charge demand was 12.9, 7.9 and 6.0, respectively.

On the other hand when chitosan was added after CFA at a dose of 1 kg/t and 1.5 kg/t, the charge demand reduced to 25.7 and 21.3, respectively.

Table 6: Effect of sequential addition of chemicals on charge demand, steaming potential and pH on OCC-1 pulp slurry at 0.33% consistency

Sequence	Steaming potential, mV	pH	Cationic charge demand, μeq/L
Pulp	-230	7.9	34.8
+ CFA, 200 g/t	-300	8.3	33.4
+ CS, 20 kg/t	-220	8.1	24.6
+ AKD, 1 kg/t	-180	8.1	18.6
+ CPAM, 200 g/t	-210	7.9	12.9
Pulp	-230	7.9	34.8
+ CFA, 200 g/t	-300	8.3	33.4
+ CS, 30 kg/t	-250	8.1	20.1
+ AKD, 1 kg/t	-200	8.0	13.1
+ CPAM, 200 g/t	-160	7.9	7.9
Pulp	-230	7.9	34.8
+ CFA, 200 g/t	-300	8.3	33.4
+ CS, 40 kg/t	-170	8.1	15.2
+ AKD, 1 kg/t	-160	8.0	10.2
+ CPAM, 200 g/t	-155	7.8	6.0
Pulp	-230	7.9	34.8
+ CFA, 200 g/t	-300	8.3	33.4
+ Chitosan, 1 kg/t	-190	7.9	25.7
+ AKD, 1 kg/t	-182	8.0	20.8
+ CPAM, 200 g/t	-175	8.0	18.9
Pulp	-230	7.9	34.8
+ CFA, 200 g/t	-300	8.3	33.4
+ Chitosan, 1.5 kg/t	-180	7.8	21.3
+ AKD, 1 kg/t	-170	7.9	16.9
+ CPAM, 200 g/t	-162	8.0	14.1

Moreover, addition of AKD and CPAM further reduced the final charge demand to 18.9 and 14.1, respectively as shown in table 6.

Initial charge demand (μeq/L) of OCC-2 was 32.7 and after addition of CFA it reduced to 28.2 whereas after addition of CS at different dose levels the charge demand was further reduced to 24.8, 24.0 and 23.1 for 20 kg/t, 40 kg/t and 40 kg/t, respectively. Final charge demand found at the mentioned dose levels after addition of AKD and CPAM were 13.6, 12.8 and 11.7, respectively. Final charge of slurry with addition of 1 kg/t and 1.5 kg/t chitosan were found as 20.3 and 18.3, respectively as shown in table 7.

Table 7: Effect of sequential addition of chemicals on charge demand, steaming potential and pH on OCC-2 pulp slurry at 0.33% consistency

Sequence	Steaming potential, mV	pH	Cationic charge demand, μeq/L
Pulp	-200	7.9	32.7
+ CFA, 200 g/t	-204	7.9	28.2
+ Cationic starch, 20 kg/t	-186	7.8	24.8
+ AKD, 1 kg/t	-182	7.9	19.5
+ CPAM, 200 g/t	-185	8.0	13.6
Pulp	-200	7.9	32.7
+ CFA, 200 g/t	-204	7.9	28.2
+ Cationic starch, 30 kg/t	-190	7.9	24.0
+ AKD, 1 kg/t	-190	7.9	18.5
+ CPAM, 200 g/t	-161	8.0	12.8
Pulp	-200	7.9	32.7
+ CFA, 200 g/t	-204	7.9	28.2
+ Cationic starch, 40 kg/t	-165	7.9	23.1
+ AKD, 1 kg/t	-160	7.9	17.2
+ CPAM, 200 g/t	-160	8.1	11.7
Pulp	-200	7.9	32.7
+CFA, 200 g/t	-204	7.9	28.2
+ Chitosan, 1 kg/t	-190	8.0	26.8
+ AKD, 1 kg/t	-190	8.0	22.4
+ CPAM, 200 g/t	-190	8.1	20.3
Pulp	-200	7.9	32.7
+ CFA, 200 g/t	-204	7.9	28.2
+ Chitosan, 1.5 kg/t	-200	7.9	24.1
+ AKD, 1 kg/t	-185	7.9	21.0
+ CPAM, 200 g/t	-185	8.0	18.3

3.3. Effect of adding different wet-end chemicals

°SR/CSF and pH of final slurry

In control set C-1, °SR/ CSF (ml) was observed to be 22/ 560 ml and pH as 7.90. The value of °SR was not significantly affected. It was found to be 21±1 in all sets of CS with OCC-1 pulp as shown in table 8. In case of chitosan in OCC-1 pulp the °SR was found to be increased by 1° when chitosan was added at a dose level of 1 kg/t at wet-end papermaking as shown in table 9. In control set C-2 °SR/ CSF (ml) was observed to be 20.5/ 585 ml and pH as 7.95. With OCC-2, °SR was not very much affected till 30 kg/t dose of CS but at a dose level of 40 kg/t, °SR was reduced to 19. In case of OCC-2, the addition of 1 kg/t chitosan with other wet-end chemicals, °SR become 21 while at a dose level of 1.5 kg/t of chitosan, °SR further increased to 22 as shown in table 10. With chitosan or CS in both OCC-1 and OCC-2 pH was found in the range 7.92±0.15.

Steaming potential / charge demand of final slurry

In control set C-1 and C-2 steaming potential (mV)/ charge demand (µeq/L) were observed as -230/ 34.8 and -200/ 32.3, respectively. After addition of different wet-end chemicals in pulp slurry the charge demand of pulp decreased. Steaming potential/ charge demand of A, B, C, D, E and F was found to be -185/ 17.5, -210/ 12.9, -200/ 10.2, -160/ 7.9, -160/ 6.9 and -155/ 6.0, respectively as shown in table 9. Similarly with OCC-2 pulp set G, H and I steaming potential/ charge demand were found as -185/ 13.6, -161/ 12.8 and -160/ 12.8, respectively. With OCC-1 pulp and 1 kg/t dose of chitosan charge was found as 18.9 whereas with OCC-2 at same dose the value was observed to be 20.3 as shown in table 10. The above result showed that due to higher charge of chitosan than CS, even when chitosan was used at low dose in wet-end, final charge of slurry was significantly affected.

Drainage time (s) of final slurry

Addition of CS at dose level 35 kg/t and 40 kg/t in OCC-1 decreased the drainage time by 2 and 3 s, respectively in comparison to control set C-1 with drainage time 18 s, whereas with OCC-2 at a dose level 30 kg/t and 40 kg/t the drop in drainage time was same i.e. 4 s in comparison to control set C-2 having drainage time 19 s. When chitosan was used in place of CS in OCC-1 at a dose of 1 kg/t the drainage time observed as 15 s which is similar to that obtained by 35 kg/t of CS. In OCC-2 with chitosan at a dose level of 1.5 kg/t the drainage time was 15 s which is better than that attained by 40 kg/t of CS as shown in table 10.

3.4. Effect of adding CS and chitosan as strength additives

Breaking length of paperboard

In control set C-1 and C-2, the breaking length was observed to be 2.05 km and 1.91 km, respectively. With the addition of CS as strength additive during wet-end papermaking, breaking length was increased. The breaking length of A, B, C, D, E and F increased by 13%, 17%, 27%, 36%, 42% and 49%, respectively in comparison to the control set C-1. Similarly, the increase in G, H and I was 21%,

Table 8: Pulp and paper properties when cationic starch used in wet-end of paperboard making

		C-1	A	B	C	D	E	F
Pulp		OCC-1						
CFA, g/t			200					
CS, kg/t			10	20	25	30	35	40
AKD, kg/t			1					
CPAM, g/t			200					
° SR		22.0	22.0	21.0	21.0	20.0	21.0	22.0
CSF		560	560	580	575	580	575	560
pH		7.90	7.90	8.03	8.04	8.08	8.01	8.02
Charge demand, µeq/L		34.8	17.5	12.9	10.2	7.9	6.9	6.0
Steaming potential, mV		-230	-185	-210	-200	-160	-160	-155
Drainage time, s	**800 ml**	18	18	17	17	17	16	15
Ash of paper, %		6.87	7.00	7.07	7.12	7.23	7.12	7.16
GSM, g/m^2		207	202	205	208	202	209	202
Bulk, cc/g		1.58	1.59	1.56	1.54	1.53	1.55	1.55
Taber stiffness		29	30	30	30	31	31	31
Cobb$_{60}$, g/m^2		330	23.1	22.5	21.8	21.2	20.6	20.2
Wax pick, Number		9	10	10	11	11	12	12

Table 9: Pulp and paper properties when chitosan used in wet-end of paperboard making

		C-1	J	K	L	M	N
Pulp		OCC-1					
CFA, g/t			200				
Chitosan, kg/t			0.30	0.50	0.75	1.0	1.5
AKD, kg/t			1				
CPAM, g/t			200				
º SR		22.0	22.0	22.5	22.5	23.0	23.0
CSF		560	560	550	550	545	540
pH		7.90	7.95	7.96	8.05	8.15	8.17
Charge demand, μeq/L		34.8	23.9	22.1	20.1	18.9	14.1
Steaming potential, mV		-230	-220	-210	-195	-175	-162
Drainage time, s	800 ml	18	17	17	15	15	14
Ash of paper, %		6.87	7.39	7.02	7.12	7.45	7.17
GSM, g/m^2		207	203	202	201	207	205
Bulk, cc/g		1.58	1.61	1.60	1.61	1.61	1.61
Taber stiffness		29	26	26	26	27	27
Cobb$_{60}$, g/m^2		330	22.7	21.2	18.9	16.2	16.1
Wax pick, Number		9	9	10	10	11	11

Table 10: Pulp and paper properties when chitosan or cationic starch used in wet-end of paperboard making

		C-2	G	H	I	J	K
Pulp			OCC-2				
CFA, g/t			200				
CS, kg/t			20	30	40		
Chitosan, kg/t						1.0	1.5
AKD, kg/t			1				
CPAM, g/t			200				
º SR		20.5	20	20	19	21	22
CSF		585	600	590	610	575	560
pH		7.95	7.90	7.91	8.11	8.02	8.01
Charge demand, μeq/L		32.3	13.6	12.8	11.7	20.3	18.3
Steaming potential ,mV		-200	-185	-161	-160	-190	-185
Drainage time, s	800 ml	19	17	16	16	15	15
Ash of paper, %		8.02	7.52	7.45	7.29	7.57	7.47
GSM, g/m^2		203	208	210	207	209	208
Bulk, cc/g		1.60	1.60	1.61	1.59	1.57	1.60
Taber stiffness		25	26	27	27	23	24
Cobb$_{60}$, g/m^2		290	22.7	22.4	21.4	17.4	17.4
Wax pick, Number		8	9	10	11	10	11

45% and 55%, respectively in comparison to control set C-2 as shown in figure 1 and 2. In case of OCC-2 the increase in breaking length at different dose levels were higher than OCC-1, the reason for this may be higher % of fines in OCC-2 which allows more retention of starch and increases the number of hydrogen bonds.

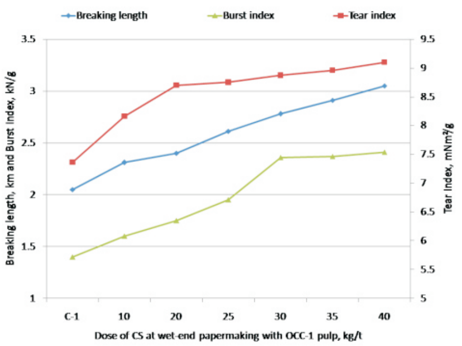

Figure - 1 : Effect of CS on strength properties of OCC-1 pulp

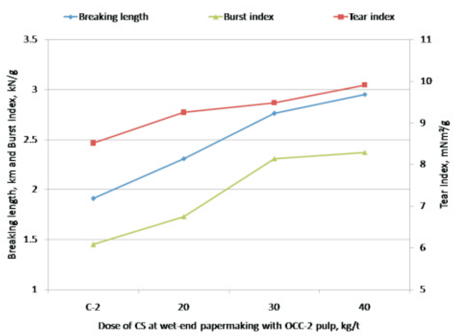

Figure - 2 : Effect of CS on strength properties of OCC-2 pulp

Chitosan addition as strength additive also increased the breaking length of paperboard in comparison to the control set. In OCC-1 the breaking length of J, K, L, M and N increased by 6%, 12%, 15%, 18% and 25%, respectively whereas in OCC-2 the breaking length of G, H and I increased by 20% and 32%, respectively as shown in figure 3 and 4. This can be attributed to more % of fines present in OCC-2.

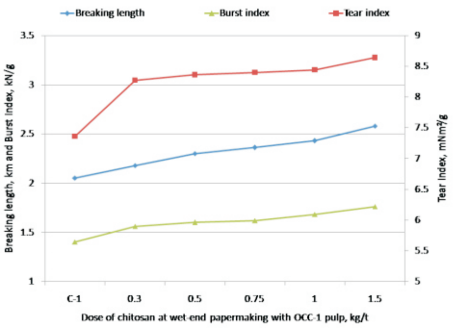

Figure - 3 : Effect of chitosan on strength properties of OCC-1 pulp

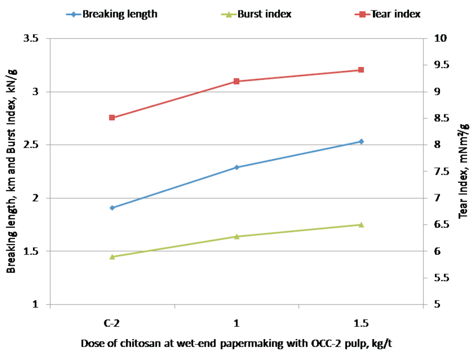

Figure - 4 : Effect of Chitosan on strength properties of OCC-2 pulp

Burst and tear indices of paperboard

Paperboard used for packaging purpose needs to have high tear and burst because generally during transportation due to different reasons like vibration, shocks, stacking etc. the chance of tearing and busting of board increases, therefore it is desired to have a paperboard with higher tear and burst properties. With addition of CS and chitosan at different doses both tear and burst indices increase. The burst index was increased by 14%, 25%, 39%, 68%, 70% and 72% for A, B, C, D, E and F, respectively. The burst index was increased by 19%, 59% and 63% for G, H and I, respectively as shown in figure 1 and 2. Similarly with chitosan burst index was increased by 11%, 14%, 16%, 20% and 26% for J, K, L, M and N, respectively. The burst index was increased by 13% and 21% for O and P, respectively as shown in figure 3 and 4. Tear index was increased by 11 % when CS was used with OCC-1 at dose of 10 kg/t and maximum when used at 40 kg/t of dose in wet-end during paperboard making. With OCC-2, CS at a dose of 20 kg/t increased the tear index by 9% and at a dose of 40 kg/t tear index was increased by 16%.

Taber stiffness, wax pick, ash and Cobb$_{60}$ of paperboard

Stiffness of paperboard was not much influenced with the addition of CS or chitosan either in OCC-1 or in OCC-2. In case of OCC-1, taber stiffness with addition of CS at a dose of 40 kg/t increased only by 2 points with respect to control set C-1 whereas in the case of chitosan, taber stiffness till the dose level of 0.75 kg/t was reduced to 3 point in reference to control set C-1 but at a dose of 1 kg/t and 1.5 kg/t, taber stiffness was reduced only 2 point in reference to control set C-1. Similar results were found with OCC-2 as shown in table 10.

Wax Pick is a number which provides the idea of the surface strength of the paperboards. In case of OCC-1, the wax pick (number) increased by 1 at a dose level of 10 kg/t and 20 kg/t CS in wet-end in reference to control set C-1. At a dose level of 25 kg/t and 30 kg/t CS with OCC-1 the wax pick number of paperboard increased by 2 whereas it increased by 3 at a dose level of 30 kg/t and 40 kg/t CS with OCC-1 in wet-end paperboard making. With chitosan in OCC-1 pulp the wax pick number increased by 1 at a dose level of 0.50 kg/t and by 2 at a dose level of 1 kg/t in wet-end paperboard making. With OCC-2 control wax pick number for set C-2 was 8, which was increased to 11 after addition of 40 kg/t CS or 1.5 kg/t chitosan as shown in table 10.

Ash (%) of paperboard with OCC-1 with both CS and chitosan was found in the range of 7.1±0.50 whereas with OCC-2 with both CS and chitosan it was in the range of 7.6±0.45. As in all cases the ash of paperboard was found almost comparable therefore the change in strength properties was all due to the strength additive i.e. CS and chitosan.

The value of $Cobb_{60}$ for control set C-1 for OCC-1 was 330 g/m^2 which reduced to 20.2 g/m^2 when 40 kg/t of CS and 1 kg/t AKD were used whereas in case of chitosan, at a dose level of 1 kg/t chitosan and 1 kg/t AKD the value was observed to be was 16.2 g/m^2 as shown in table 9. The value of $Cobb_{60}$ for control set C-2 for OCC-2 was 290 g/m^2 which was reduced to 21.4 when 40 kg/t of CS and 1 kg/t of AKD were used whereas in case of chitosan, at a dose level of 1 kg/t chitosan and 1 kg/t AKD the value was reduced to 17.0 g/m^2. The result of $Cobb_{60}$ showed that the efficacy of AKD was improved in the presence of chitosan.

4. Conclusion

Charge demand of chitosan was higher than that of CS due to which even when chitosan was used at a lower dose it was able to reduce the charge of the final pulp slurry for making paperboard. Drainage time after addition of 1.5 kg/t of chitosan with both OCC-1 and OCC-2 was found better than that obtained with 40 kg/t of CS with both pulps. Efficacy of AKD was also found better in the presence of chitosan than CS with both pulps. Improvement in breaking length of OCC-1 pulp after addition of CS at a dose level of 20 kg/t was almost comparable to that attained with chitosan at a dose level of 1 kg/t. Tear and burst indices attained by OCC-1 pulp after addition of 1.5 kg/t of chitosan were found comparable with those attained by 20 kg/t CS with OCC-1. Similar results were obtained with OCC-2 also, the tear and burst indices attained after addition of 1.5 kg/t of chitosan were comparable with those obtained with 20 kg/t of CS with OCC-2.

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