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Characteristics of Pulp and Paper Produced from Corn Stalk

Jong Myoung Won† and Aziz Ahmed*1

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ABSTRACT

Corn stalk was evaluated to verify the potential as a raw material for papermaking. The lower lignin content and higher hemicelluloses content of cornstalk than any woods were considered to be beneficial for pulping and strength properties of paper. The average fiber length of corn stalk was similar to those of hardwood, but longer fiber fraction is little bit included. It was found that the refining of pulp can be eliminated because of higher hemicelluloses content and narrower fiber characteristic. Disadvantages of cornstalk pulp were lower bulk and opacity, but it can be overcome by the proper use of wood pulp and filler.

Keywords: corn stalk, fiber length, pith, lignin, hemicelluloses, pulping, bleaching, mill trial, strength properties

1. Introduction

Woods are the major source of fiber supply in the United States, Canada, Brazil, Indonesia, and in many other countries of the world where forests resources are abundant, for the pulp and paper industry. Wood fiber has better qualities and economical benefit than other materials. Softwood fibers have long fiber length, and are used for paper products where high strength is important. Hardwood fibers have much shorter fibers, and are suitable in paper products where formation, printability and optical properties are important, such as writing and printing paper. However, industrial development and urbanization caused the increased emission of greenhouse gases, devastation of the forests, thus made the environment worse. This environmental situation incurred global warming, unexpected climate change, disorder of ecological system. Therefore, there are several campaigns including recycling of wastepaper, introduction of LCA into the manufacturing industries, and so on for the environmental protection. Utilization of recycled fiber in paper and paperboard manufacture continues to grow for both economical and environmental reasons. However, recycled fiber could not meet fully the requirement in paper industry. The recycle

• Dept. of paper science & Engindering, College of Forest Sciences, Kangwon National University, Chuncheon 200-701, Korea
*1 Forest Products Laboratory, Forest Service-USDA, One Gifford Pinchot Drive, Madison, WI 53726-2398, U.S.A
† Corresponding author: E-mail; wjm@kangwon.ac.kr

cause the hornification of chemical pulp fiber, and repeated recycling damages fiber, which limits the amount of recycled fiber that can be used. These limitations indicate the need for an alternative source of fibers for papermaking.

Another possible mean that can protect the environment is to use agricultural waste, and / or annual plants as a raw material in the production of paper and paper products. The use of non-wood fiber as a raw material in paper industry is not new. The use of non-wood pulp including rice straw, wheat straw and bamboo in China paper industry is correspond to about 16 millions tons per year, although their qualities are much inferior to wood fiber. Studies on the pulping and papermaking of corn stalk are carried out in several countries. Their results showed that pulp and paper qualities are similar to hardwood fiber. However, the commercialization of corn stalk pulping for fine paper seems to be not successful because of several reasons (i.e., dewatering, pulp qualities, etc.). The objective of this study is to investigate the potential of the corn stalk as a raw material for the production of fine paper.

2. Characteristics of Corn stalk

Corn stalk has very different properties from wood as in other non-woody plants. Lower lignin content of cornstalk than any woods is very interested. This indicates that the pulping of corn stalk is easier than wood. Higher hemicelluloses content will be beneficial in refining, fiber bonding and strength properties. Average fiber length is similar to hardwood fiber, but longer fiber fraction is little bit included. This longer fraction can contribute to strength properties. The average fiber width of corn stalk was narrower than both softwood and hardwood fiber. The corn stalk fiber will has higher flexibility and conformability because of narrower fiber structure, and thus very dense sheet will be obtained. This sheet structure will bring about the lower opacity and bulk. The characteristics of softwood, hardwood and corn stalk are shown in Table 1.

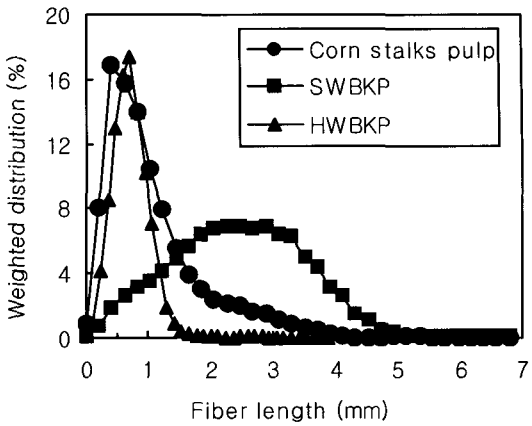

Fig. 1. Fiber length distribution of softwood, hardwood, and corn stalk.

Table 1. The characteristics of wood and corn stalk

Source	Average		Cellulose (%)	Pentosan (%)	Lignin (%)
	Length (mm)	Width (μm)			
Softwood	2.7-4.6	32-43	40-52	8-12	26-32
Hardwood	0.7-1.6	20-40	38-50	15-25	18-28
Cornstalk	1.0-1.5	18-22	46-50	27-28	16-17

Huge amounts of corn stalk are produced as shown in Table 2. However, only a part is used as a feedstock, and the rests are usually crashed and spread on the field as a soil conditioner. If the corn stalk is used as a pulping raw material, ca 178.65 million tons of chemical pulp can be produced. This amount is corresponded to ca. 150% of wood chemical pulp supplied at 2002. Therefore, if a half of corn stalk available is used in the production of pulp for papermaking, we can substitute

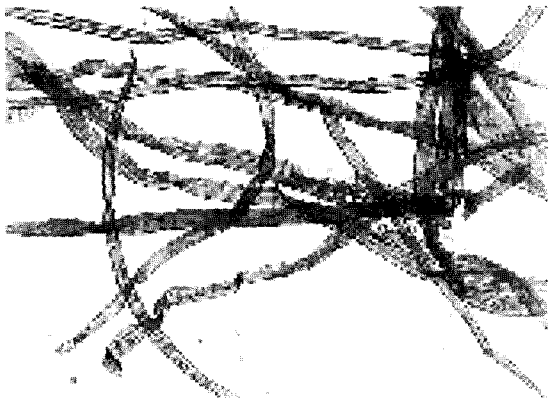

Fig. 2. Micrograph of SwBKP.

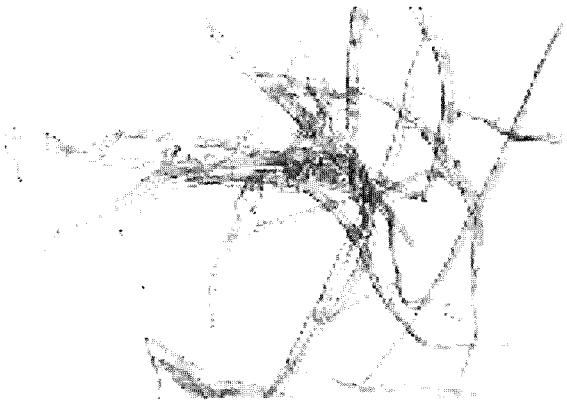

Fig. 3. Micrograph of HwBKP.

Fig. 4. Micrograph of corn stalk pulp.

about 70% of wood chemical pulp, and thus can preserve the forest resources.

Table 2. Estimated production of corn stalk and chemical pulp

	Cultivation area (1000 ha)	Corn stalk production (1000 tons)	Possible pulp production (1000 tons)
World	350,300	446,633	178,653
United States	71,310	90,939	36,376
China	64,760	82,586	33,035

3. Materials and Methods

3.1 Raw materials

Corn stalks grown in Korea(Chuncheon), United States(Madison, Wisconsin), and China (Kaiyuan, Liaoning) are used for pulping. Corn stalks were cut off after harvesting and air-dried. Leaves and pith are removed manually, and break into small pieces before laboratory-scale pulping and mill trial. Pith fraction was ca. 23% in dry weight basis. Bottom part of corn stalk is used for pilot pulping without crashing, and pith is not removed.

3.2 Experimentals

Corn stalk grown in Korea is used for lab-scale trial 1. Soda and kraft pulping were carried out by laboratory digester (400 g capacity). Both types of cooking were carried out at 150℃ for 60 min. Liquor ratio applied was 7:1. Five stage ((C+D)EDEP) bleaching is carried out for soda pulp (15% active alkali) because there was not so much difference between soda and kraft process. Handsheets (60 g/m^2) for physical testing were prepared from bleached corn stalk soda pulp and its mixture with SwBKP.

Corn stalk grown in United States is used for lab-scale trial 2. The pith was separated from corn stalk completely, and pith fractions are added to verify the effects of pith fraction on the paper properties. Pilot pulping was carried out at 25 kg capacity of digester. Same cooking condition as lab-scale trial was applied for pilot pulping. This pulp was compared with wood pulp at pilot papermachine.

Mill trial was done at Kaiyuan pulp and paper mill (Liaoning, China). Digester used was rotating spherical type, and capacity was 4 tons. Alkaline sulfite pulping system was applied for mill trial as they did. The pulp was bleached with 6% of hypochlorite because they have only one stage bleaching system. Machine-made papers (70 g/m^2) were produced from the mixture of bleached corn stalk pulp and SwBKP at fourdrinier paper-machine. Talc and rosin size emulsion is used, and surface sizing was applied.

4. Results and Discussion

4.1 Lab-scale trial 1

Soda process is usually used for the pulping of non-woody plants. Any benefits from kraft process in the pulping of cornstalk were also not observed in our lab-scale experiments. Our result showed that the delignification by soda process was easier than kraft process (Table 3). The screened yield and reject in soda

Table 3. Pulping characteristics of corn stalk

Pulping process	Active alkali(%)	Screened yield(%)	Reject (%)	Kappa no.	Freeness (CSF, ml)
AP	13	47.75	0.76	14.09	602
	15	47.17	0.14	11.66	595
KP*	13	46.77	0.14	11.66	616
	15	47.96	0.39	12.72	599

* Sulfidity: 20%

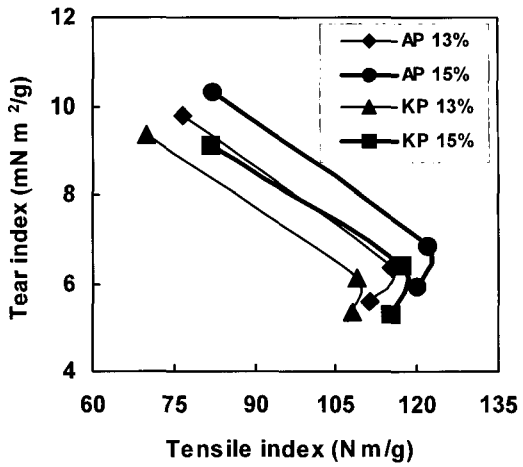

Fig. 5. Relationship between tensile index and tear index of unbleached corn stalk pulp sheet.

pulping were similar to kraft pulping, although the freeness of soda pulp was lower than kraft pulp.

Apparent density of unbleached corn stalk pulp sheet was similar at same freeness level whatever the pulping processes were applied (Table 4). However, very interesting things are that strength properties of soda pulp sheet were higher than those of kraft pulp sheet in the usual range of apparent densities. It was also found that higher tear index at certain tensile index can be obtained by soda pulping (Fig. 5). Corn stalk soda pulp is compared with softwood and hardwood pulp to verify its potential as a papermaking raw material (Table 5). As one can expect from the characteristics of corn stalk fiber, it is not recommended to use corn stalk pulp alone as a papermaking raw material except for the case of specialty papers. Unbeaten cornstalk pulp has already relatively high strength properties due to the thin-walled fiber structure and high hemicelluloses content. Slight refining increased the strength properties significantly, and showed similar value to those of paper made from wood pulp

Table 4. The properties of paper made from unbleached corn stalk soda and kraft pulp

Process	Active alkali(%)	Freeness (CSF, ml)	Apparent density (g/cm^3)	Tensile index (N·m/g)	Tear index ($mN·m^2/g$)	Burst index ($kPam^2/g$)	Stiffness (g_f cm)	Brightness (%)	Opacity(%)
AP	13	602	0.611	76.7	9.77	4.32	2.55	32.4	95.6
		400	0.754	115	6.38	7.06	2.08	29.8	91.0
		300	0.767	111	5.57	6.47	2.23	28.6	89.0
	15	595	0.615	82.3	10.3	4.68	2.73	35.7	95.3
		400	0.735	122	6.83	7.68	2.08	33.1	91.5
		300	0.794	120	5.94	7.03	2.35	32.6	88.1
KP	13	616	0.597	69.8	9.37	3.83	2.18	28.3	96.6
		400	0.746	109	6.10	6.31	2.03	25.2	93.1
		300	0.787	108	5.37	6.26	2.10	24.4	91.2
	15	599	0.616	82.0	9.09	4.87	2.48	32.8	96.0
		400	0.738	117	6.41	7.02	2.23	30.3	91.7
		300	0.777	115	5.30	6.63	2.30	29.1	87.8

Table 5. Physical properties of paper made from bleached corn stalk soda pulp and its mixture with SwBKP

	Apparent density (g/cm^3)	Tensile index (N·m/g)	Tear index ($mN·m^2/g$)	Burst index ($kPam^2/g$)	Stiffness (g_f cm)	Brightness (%)	Opacity (%)
Unbeaten corn stalk	0.64	42.6	10.5	2.42	1.87	84.1	77.1
Beaten corns talk	0.74	67.3	7.63	3.88	1.93	83.2	72.1
Corn stalk : SwBKP (90 : 10)	0.75	75.0	7.74	4.29	1.47	83.2	71.1
Corn stalk : SwBKP (80 : 20)	0.74	74.9	9.37	4.62	1.93	83.1	71.3
HwBKP : SwBKP (80 : 20)	0.69	66.8	8.62	3.78	2.03	80.6	78.3

* Freeness of corn stalk pulp and wood pulp were controlled to 400 ml CSF.

only except for high apparent density. A small addition of SwBKP increased much more, and even gave higher strength properties than those obtained from the mixture of HwBKP and SwBKP. This result showed the possibilities that paper properties could be improved further by the proper combination with wood pulp.

4.2 Lab-scale trial 2

In this experiment, the effects of pith fraction on the pulp qualities was considered (Table 6). The addition of pith fraction seems to be not harmful, but this can cause some problems, because pith fraction contains much shorter fiber fraction. Kappa no. of corn stalk soda pulp was only around 8, which is much less compared to wood pulp (hardwood pulp 18-20; softwood pulp 28-30). This means that corn stalk pulps consume lesser chemicals for bleaching and require less bleaching step than those of similar wood pulp. Three stages (DED) of bleaching sequence were enough to get brightness of around 82% ISO, and four stages (DEDP) of bleaching sequence increased the brightness 5% more. However, further bleaching (hydrogen peroxide sequence) caused

Table 6. Effect of pith fraction on the pulping and paper properties

Pith content (%)	Active alkali (%)	Screened yield (%)	Freeness (CSF, ml)	Apparent density (g/cm^3)	Tensile index (N·m/g)	Tear index (mN·m^2/g)	Burst index (kPam^2/g)	Brightness (%)	Opacity (%)
0	13	45	360	0.817	96	5.9	6.5	38	85
	14	46	436	0.807	94	6.8	6.2	40	86
	15	45	370	0.830	96	6.2	6.5	40	86
15	13	44	360	0.847	90	6.5	5.9	39	83
	14	45	360	0.865	91	5.8	6.1	39	84
	15	44	370	0.845	91	5.9	6.0	38	83
23	13	44	443	0.757	90	5.3	5.6	39	89
	14	44	440	0.788	94	6.6	5.9	39	89
	15	45	467	0.786	93	6.0	5.8	40	89

Table 7. Physical properties of paper made from bleached corn stalk soda pulp

Bleaching sequence	Freeness* (CSF, ml)	Apparent density (g/cm^3)	Tensile index (N·m/g)	Tear index (mN·m^2/g)	Burst index (kPa m^2/g)	Brightness (%)	Opacity (%)
DED	320	0.866	104	7.4	7.2	82.4	61
DEDP	335	0.875	91	5.8	5.9	87.2	61

* Freeness of bleached cornstalk soda pulp was 540 ml CSF

the decrease of strength properties significantly.

4.3 Pilot-scale trial

Pilot pulping and bleachability were similar to the result of lab-scale trial, although the bottom part of corn stalk was used without the removal of core fraction. We found that refining demand of pith stalk soda pulp was exceptionally lower than those of wood pulp (Table 8). Paperma- king properties of bleached corn stalk soda pulp were compared to the wood pulp at pilot papermachine (Table 9). Most strength proper- ties of paper obtained from the mixture of bleached corn stalk soda pulp and SwBKP were higher than those of paper obtained from the mixture of HwBKP and SwBKP.

4.4 Mill trial

Mill trial was carried out to confirm the result obtained from lab-scale trial. We could confirmed that the delignification during pulping and bleaching were easier than wood and rice straw. The freeness of bleached corn stalk pulp was ca. 500 ml CSF, and there were no problems in dewatering at all. The physical properties of paper produced at Kaiyuan paper

Table 8. Physical properties of unbleached corn stalk soda pulp sheet produced at pilot scale digester

Freeness (ml, CSF)	Apparent density (g/cm^3)	Tensile index (N m/g)	Tear index (mN m^2/g)	Burst index (kPa m^2/g)
380	0.674	83	4.2	5.7
360	0.733	82	4.5	5.4
350	0.728	81	4.5	5.4

*1 Active alkali 14%.
*2 Pulp was refined with PFI mill(400, 700, 1000 revolutions respectively).

Table 9. Paper properties obtained from bleached corn stalk soda pulp and wood pulp at pilot papermachine trial

		Grammage (g/m^2)	Ash(%)	Apparent density (g/cm^3)	Tensile Index (N m/g)	Tear Index ($mN\ m^2/g$)	Burst Index ($kPa\ m^2/g$)	Stiffness (g_f cm)	Smoothness (Sheffield)	Opacity (%)
HwBKP+ SwBKP*1	MD	80.4	17	0.698	26.7	3.8	0.8	1.70		89.8
	CD				12.0	4.7		0.71		
	Felt								155	
	Wire								160	
Corn stalk+ SwBKP*2	MD	76.9	22	0.784	42.3	5.9	1.74	1.63		87.2
	CD				25.5	6.4		0.91		
	Felt								157	
	Wire								143	

*1 HwBKP 60%, SwBKP 20%, PCC 20%
*2 Bleached corn stalk soda pulp 60%, SwBKP 20%. PCC 20%
*3 Wood pulp was refined to 400 ml CSF, but bleached corn stalk pulp did not refined.

Table 10. Physical properties of paper produced at Kaiyuan paper mill

Properties		Corn stalk 70 : SwBKP 30*1	Corn stalk 80 : SwBKP 20*1	Corn stalk 100	American copy paper
Grammage (g/m^2)		71.6	71.6	72.8	77.3
Apparent density (g/cm^3)		0.88	0.91	0.81	0.76
Ash (%)		28.45	31.2	5.57	12.12
Tensile index (N m/g)	MD	49.7	46.5	63.2	58.6
	CD	22.5	24.1	34.6	26.0
Tear index ($mN\ m^2/g$)	MD	4.9	4.4	5.3	7.4
	CD	4.4	3.9	4.8	7.3
Burst index ($kPa\ m^2/g$)		2.1	1.8	2.8	2.7
Stiffness (g_f cm)	MD	1.23	1.12	2.0	2.0
	CD	0.68	0.73	1.1	1.1
Smoothness (Sheffield)	Felt	186	152	187	169
	Wire	115	98	129	154
Brightness (%, ISO)		83.8	82.6	76.5	80.1
Opacity (%)		79.3	80.7	78.4	87.8

mill were compared with American copy paper (Table 10). Although there were many limitations (ie., filler quality, system control of paper machine, etc.), we could confirmed that corn stalk pulp can substitute a part of wood pulp without the significant deterioration.

5. Conclusions

Corn stalk was evaluated to verify the potential as a raw material for papermaking. Average fiber length of corn stalk was similar to those of hardwood, but small amount of long

fiber fraction was observed. The important features of corn stalk are higher hemicelluloses content and lower lignin content than those of wood. Therefore, the less cooking and bleaching chemicals are required to get good quality of pulp. Another important thing is that corn stalk pulp does not require the refining. Deflaking was enough to get enough strength properties. Disadvantages of corn stalk pulp were lower bulk and opacity, but it can be overcome by the proper combination of wood pulp and filler.

Acknowledgements

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