Role of Strength Aids in Increasing Ash in Paper Prepared From Bleached Wheat Straw Pulp

Sharma Ashish, Kumar Sudhir, Chauhan Vipul S., Chakrabarti Swapan K. & Varadhan R.

Thapar Centre for Industrial Research & Development, Yamuna Nagar - 135 001, Haryana, (India)

ABSTRACT

Indian papermakers are struggling to increase filler content in paper so as to reduce cost and to achieve desirable properties of paper. The increasing cost of virgin pulp and the energy associated with its transformation to paper are familiar problems to the paper industry. Moreover, shortage of hardwood fiber has forced the paper industries to think for agro-residue based pulps. A major constraint in increasing ash in paper beyond a limit is the impairment of inter-fiber bonding on filler loading, and the resulting decrease in paper strength. The morphology and ionic behavior of fillers are important parameters in papermaking. The present communication is related to increasing ash in paper made from bleached wheat straw pulp using talc and ground calcium carbonate (GCC) as fillers. The fillers were loaded in paper at 21% and 24% ash level using appropriate retention aid. Two cationic and amphoteric dry strength additives were used to compensate the strength loss in paper to some extent on increasing filler content in paper. The ash can be increased by increasing the filler content along with increased dose of dry strength additives without compromising the strength properties. However, this trend was different for different fillers.

Keywords: *Wheat straw pulp, ash, strength additive, paper strength, Talc, GCC*

Introduction

The aim of the papermaker is to raise the filler content to the extent possible due to the scarcity of fibrous raw materials and increasing prices. The cost of fibrous raw material is increasing with time, whereas availability is decreasing due to environmental and other various factors. Filler is cheaper as compared to fiber and is very common to use in papermaking to reduce the paper cost. It is usually used in papermaking to provide cost and energy savings [1], and to improve optical properties, sheet formation, smoothness, printability, dimensional stability, and appearance of papers [2-9].

Loading of filler in the paper matrix also contribute to the adverse effect to paper strength by directly interfering with interfiber bonding [10]. The use of filler depends upon fiber quality, process parameters and conditions, wet-end chemicals and the end use of paper [9]. Papermakers wish to increase filler in paper so as to reduce cost and achieve desirable functional and optical properties of paper. But, there are some limitations, mainly drop in strength properties, in use of filler beyond a certain level.

Fillers can generally be divided into two groups, inorganic fillers and organic fillers. The dominant fillers used in papermaking are inorganic fillers. Organic fillers are of two main types, hollow micro-spheres and porous fillers. They are suitable only for special applications because of high price. The high-filler content papers are commonly referred as "high-ash paper. A major constraint in making high-ash paper is the impairment of inter-fiber bonding, and the resulting decrease in paper strength [4,9,11]. It is generally considered that the use of inorganic fillers, especially at high loading levels, has the following disadvantages or limitations:

- Paper strength is inevitably reduced by replacement of the fibers by inorganic fillers, not only because there are less fibers in the sheet, which reduces the number of fiber-fiber bonds in the sheet, but also because the presence of the filler reduces the area of contact between the remaining fibers.
- Increased loading of inorganic fillers have negative effects on filler retention, resulting in higher solids content of the circulating system.
- It has negative effects on sizing efficiency of the filled papers, increasing the demand for sizing agents.
- Use of inorganic fillers can cause abrasion and dusting under certain conditions.

By the introduction of special chemical additives, the retention can be improved considerably. The particles then become attached to the fiber surface by co-flocculation and agglomeration of filler particles buildup of the web [12].

Because of above mentioned hurdles, it is very important to study all aspects to increase filler in paper without or with minimal strength loss. Papermakers are also working on new developments on filler modification to retain more filler in paper without affecting strength properties. A fibrous filler was developed that may produce a composite paper containing up to 50% ash with equal or better performance characteristics than conventionally attainable [13]. Loading filler in the lumen and cell wall of fibers is also a new area of research [14,15]. The preflocculation of filler particles prior to its addition to paper has been reviewed by Chauhan et al [8] which shows several benefits in papermaking.

Paper relies for its strength on the area of intimate fiber contact brought about and maintained in the pressing and drying phases and, of course, to an extent on the inherent strength of the fibers. The fiber-to-fiber bonds are believed to be essentially hydrogen bonds and the dry strength additives can contribute to the same type of bonding. An increase in strength may theoretically be brought by increasing the area of contact or by improving the absolute or specific bond strength of a given area of contact. When the area of contact is increased by an additive, the mechanism of strength improvement may be thought of as similar to the effect of beating with similar benefits in strength. It is always good to evaluate the effects of the dry strength additive on paper prior to a full scale paper machine trial [16]. Increase in paper strength by the use of strength additives enhances the scope of ash increase in paper.

In India, the filler content in paper is much lower as compared to filler content in paper manufactured abroad. The reason could be the suitability of filler with wet end chemicals (mainly dry strength additives and retention aids) and fiber i.e. hardwood, agro-residues and recycled fibers. The morphology and the ionic behavior are also very important in the selection of filler. The fiber length of Indian raw material is comparatively lower, thus strength drop is higher with the addition of filler [9]. In common practice around 20% ash is kept in paper made in India with agro residue pulps such as wheat straw and bagasse. In the present communication, the effect of most commonly used fillers (talc and GCC) on agro-residue pulp (wheat straw) has been studied along with two types of dry strength additives; cationic and amphoteric. The dry strength additives were used at different dosage levels to protect the strength loss of paper to some extent on increasing the filler content in paper.

Experimental

Materials

Agro-residue based pulp; bleached wheat straw was sourced from an integrated pulp and paper mill in northern India. The AKD used as sizing agent had 15% solids. Medium to high molecular weight cationic polyacrylamide (CPAM) was used as retention aid. Low molecular weight cationic polyamine was used as cationic fixing agent. The cationic strength additive (CSA) and amphoteric strength additive (AmSA) were used as dry strength additives. Two different fillers viz., talc and GCC were used at different addition levels to get varying ash in paper.

Methods

The bleached wheat straw pulp was having around 27 ^{0}SR and used as such without beating. The fillers were dispersed in water (20% w/v) for 30 minutes prior to its addition into pulp stock. The strength additives were cooked to prepare 1% (w/v) slurry. The cooking of CSA and AmSA was performed at 90^{0}C. The CPAM was dissolved in water at 40^0 C for 30 min at 300 rpm to prepare a solution of 0.1% (w/v). It was used at a fixed dosage of 200 g/t of pulp with all the fillers. The arbor press was used to compact the moisture free fillers in the disc prior to measure the optical properties in Datacolor (Spectraflash 300) brightness tester.

The colloidal charge or ionic behavior of 10% (w/v) slurry of fillers was examined on Mutek particle charge detector (PCD 03 pH). The surface charge on fillers was determined in the form of zeta potential on Mutek system zeta potential meter (SZP 06). About 500 ml of filler sample (10% w/v) was taken and mixed thoroughly before measurement. The particle size distribution of the fillers was measured on laser scattering particle size distribution analyzer (Horiba LA 950S2). The talc filler wetted with ethanol whereas GCC was dispersed in deionized water with sodium hexa meta phosphate to make 10% (w/v) slurry.

Paper handsheets of 70 g/m^2 were prepared on lab handsheet former as per Tappi Test Method T 272 sp-97. Sheets pressing and drying were done according to Tappi Test Method T 218 sp-02. The conditioning of sheets was done at 23±1^{0}C and 50±2% relative humidity for 8 hours following Tappi Test Method T 402 sp-98.

The ash content of the hand sheet was determined as per Tappi Test Method T 211 om-93 at 525^{0}C. The first pass ash retention (FPAR) was calculated from the ratio of ash in paper to ash in head box. The properties of paper were tested as per Tappi/ISO test methods.

Results & Discussion

The brightness of GCC was higher than that of talc. The difference in brightness of GCC and talc was around 4.3 units. GCC was finer than talc filler. The fractions of GCC and talc, below 2 µm particle size were 27.6 and 0% respectively. The median particle size of GCC and talc was 3.0 and 9.9 µm respectively. It was confirmed from the results of both colloidal charge and zeta potential that GCC was cationic in nature, whereas talc was anionic. The charge demand of GCC was more than that of talc. GCC was having anionic charge demand of 6.5 µeq/g while talc was having cationic charge demand of 1.7 µeq/g (Table 1).

Table 1: Physico-chemical properties of fillers

Parameter	Talc	GCC
ISO brightness, %	89.7	94.0
Particles less than 2 µm, %	0	27.6
Particles less than 5 µm, %	4.3	79.9
Particles less than 10 µm, %	50.7	98.4
Median particle size (D50), µm	9.9	3.0
Chemical formula	$3MgO.4SiO_2.H_2O$	$CaCO_3$
Charge demand, µeq/g	1.72 (cationic)	6.50 (anionic)
Zeta potential, mV	- 267	+ 401

In India, most of the fine grade papers from agro residue pulps are produced with around 18 to 20% filler content. Paper makers also use some amount of strength additives to compensate the strength loss to some extent which occurs on filler loading. In this study, two reference paper sheets were produced with 21 and 24% filler content; cationic strength additive (CSA) was used at 5 kg/t dose level. The different dosage of CSA and AmSA were used at both the ash levels with both talc and GCC fillers. The increment/decrement in the paper properties on addition of different dosage of strength additives has been compared in the following section of the paper.

Effect of filler on FPAR

The higher filler retention was observed with talc followed by GCC. At 5 kg/t dosage of CSA, the requirement of talc and GCC to get 21% ash in paper was 310 and 350 kg/t respectively which showed that in case of GCC filler an extra amount of filler (13%) was required to get the same ash in paper as compared with talc (Table 2). Similarly, the requirement of talc and GCC to get 24% ash in paper was 390 and 420 kg/t respectively. The FPAR of both talc and GCC fillers increased on increasing the dosage of CSA.

As shown in Figure 1 the gain in FPAR was more in case of talc filler than that of GCC with both the strength additives. On comparing at 21% ash, the gain in FPAR of 3.0 and 2.0% was observed in case of talc filler while this gain was 0.1 & 1.4% in case of GCC at 10 & 15 kg/t dosage of CSA respectively. On comparing at 24% ash level, the gain in FPAR was 2.6 and 1.1% with talc filler at higher doses of CSA while in case of GCC filler the gain could not be achieved even at 15 kg/t of CSA dose.

In case of AmSA also the gain in FPAR was lesser in case of GCC than that of talc filler. About 2.5% gain was observed at AmSA dosage of 5 & 10 kg/t in comparison to the first reference with talc filler at 21% ash while 0.9 and 5.8% gain was observed at 24% ash level at the same doses of AmSA. With GCC filler the gain in FPAR with AmSA at 5 and 10 kg/t was around 1%.

Table 2: Properties of paper from bleached wheat straw pulp with 5 kg/t dosage of CSA at 21 and 24% ash

Parameter	Talc		GCC	
Flier addition, kg/t	310	390	350	420
Ash, %	21	24	21	24
FPAR	85.5	85.3	72.2	73.8
Breaking length, m	3278	3186	2901	2797
Burst index, kN/g	1.93	1.75	1.90	1.67
Tear index, mNm^2/g	3.50	3.33	4.33	3.95
ZDTS, kPa	701	632	634	594

Effect of filler on breaking length

The fiber-fiber bonding decreased with the lowering of particle size of filler. The similar trend was reported elsewhere [3]. As shown in Table 2, the breaking length of paper made from BWS pulp was higher with talc filler than that with GCC at same level of ash and CSA. Between the two strength improving additives; CSA and AmSA it was observed that breaking length increased marginally with AmSA as compared to that with CSA while talc was the filler. The similar results were reported elsewhere [9]. The effect of CSA on increment in breaking length when GCC was used as filler was higher as compared to that of AmSA with GCC.

In the first reference at 21% ash, with talc and GCC at 5 kg/t dosage of CSA the breaking lengths of paper were 3278 and 2901 m respectively. The corresponding breaking lengths at second reference at 24% ash were 3186 and 2797 m respectively. A decrease of 2.8 and 3.6% in breaking length was observed on increasing ash from 21 to 24% with talc and GCC respectively (Table 2). In comparison to the first reference of 21% ash, the increase in breaking length of paper with talc along with 10 and 15 kg/t dosage of CSA was 4.9 and 9.2% respectively (Figure 2).

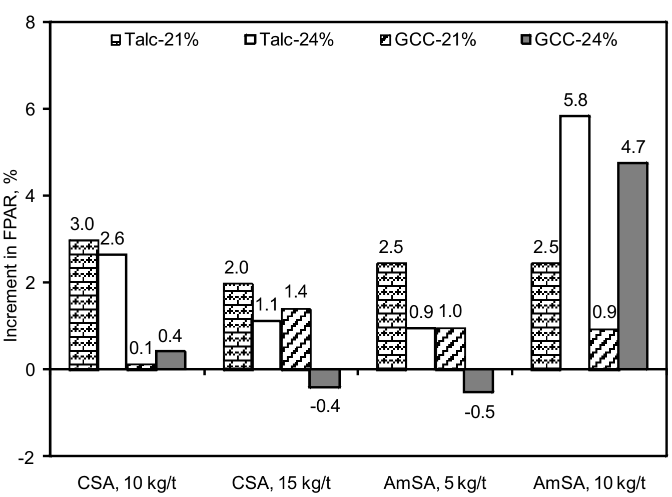

Figure 1: Increment of FPAR in paper made from bleached wheat straw pulp with addition of different strength additives as compared to the reference (5 kg/t of CSA at two ash levels i.e. 21% and 24% with same filler)

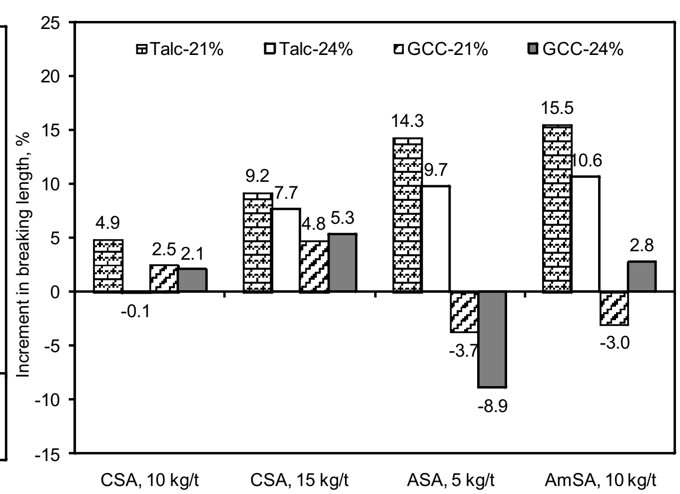

Figure 2: Increment in breaking length of paper made from bleached wheat straw pulp with addition of different strength additives as compared to the references (5 kg/t of CSA at two ash levels i.e. 21% and 24% with same filler)

The breaking length of filled paper at the same ash level increased on increasing dosage of CSA. The gain in breaking length of paper was higher in case of talc filler than that of GCC at both ash levels i.e. 21 and 24%. At 10 and 15 kg/t of CSA and 21% ash with talc filler, the increment in breaking length was 4.9 and 9.2% respectively. While using GCC filler at same dosage of CSA at 21% ash level the gain in breaking length was 2.5 and 4.8%.

When the breaking length with talc filler was compared at 21% ash level with different dosage of strength additives, it was observed that the highest increment in breaking length was achieved with 10 kg/t dosage of AmSA (15.5%) followed by 5 kg/t of AmSA (14.3%), 15 kg/t dosage of CSA (9.2%) and 10 kg/t dosage of CSA (4.9%). The similar trend was also observed at 24% ash level with talc filler.

In case of CSA and GCC filler, the increase in breaking length as compared to the first reference of 21% ash was also observed on increasing the dosage of CSA. It was 2.5 and 4.8% with 10 and 15 kg/t dosage of CSA. However, the breaking length of paper decreased with the addition of AmSA.

Effect of filler on burst index

In the first reference i.e. 21% ash with talc and GCC at 5 kg/t dosage of CSA as strength aid, the burst index of paper was 1.93 and 1.90 kN/g respectively. The corresponding burst index of second reference i.e. at 24% ash was 1.75 and 1.67 kN/g respectively. A drop of 9.3 and 12.1% in burst index was observed on increasing ash from 21 to 24% with talc and GCC respectively (Table 2).

At 21% ash level, the gain in burst index was more in case of GCC than talc filler by increasing the dose of CSA to 10 and 15 kg/t as compared to the references. On comparing with the first reference, the gain in burst index of 3.1 and 7.3% was observed in case of talc filler while this gain was 7.4 & 14.2% in case of GCC at 10 & 15 kg/t dosage of CSA respectively at 21% ash. On comparing with the second reference at 24% ash level the gain in burst index was 19.8 and 24% with GCC filler at 10 and 15 kg/t dosage of CSA while in case of talc filler the gain could be achieved only at 15 kg/t of CSA dose at this ash level (Figure 3).

In case of AmSA, the gain in burst index was lesser than that of CSA with talc filler. About 11.4% gain was observed at AmSA dosage of 10 kg/t in comparison to the first reference with talc filler at 21% ash while 2.1 and 17.1% gain was observed at 24% ash level at the same doses of AmSA. With GCC filler the gain in burst index with AmSA was lesser than that of CSA (Figure 3).

Effect of filler on tear index

The tear index of paper was lower with talc filler as compared to that with GCC filler. In the first reference i.e. 21% ash with talc and GCC at 5 kg/t dosage of CSA as strength aid, the tear index of paper were 3.50 and 4.33 mNm^2/g respectively. The corresponding tear indexes at second reference at 24% ash were 3.33 and 3.95 mNm^2/g respectively. A drop of 4.8 and 8.8% in tear index was observed on increasing ash from 21 to 24% with talc and GCC respectively (Table 2).

At 21% ash in comparison to the first reference, the increase in tear index was observed with GCC only. By increasing the dose of CSA from 5 to 10 kg/t the drop in tear index was observed with talc but with GCC a gain of 0.7 and 1.8% at 21 and 24% ash level was observed respectively. AmSA as strength additive had not given positive effect on tear index with either of filler i.e. talc and GCC (Figure 4).

Effect of filler on Z-direction tensile strength

The Z-directional tensile strength (ZDTS) represents the structural rigidity of a sheet of paper when subjected to tensile stress in the out of plane or Z-direction. It is a measure of the internal fiber bonding strength of a substrate [9].

In the first reference i.e. 21% ash with talc and GCC at 5 kg/t dosage of CSA the ZDTS of paper was 701 and 634 kPa respectively. The corresponding ZDTS at second reference at 24% ash was 632 and 594 kPa respectively. A drop of 9.8 and 6.3% in ZDTS was observed on increasing ash from 21 to 24% with talc and GCC respectively (Table 2).

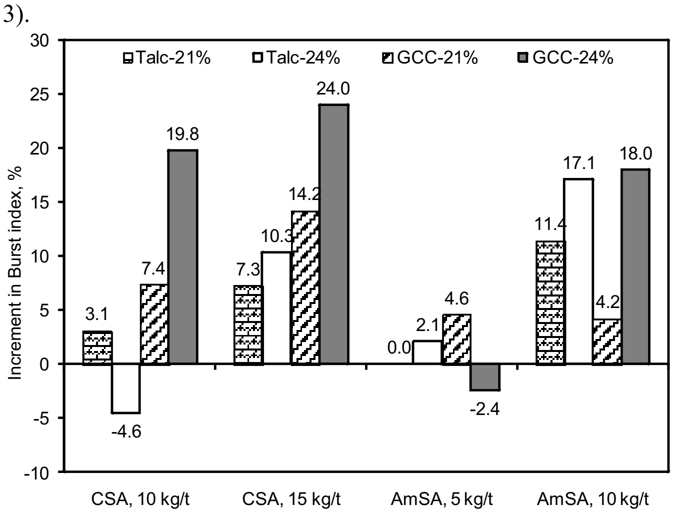

Figure 3: Increment in burst index of paper made from bleached wheat straw pulp with addition of different strength additives as compared to the references (5 kg/t of CSA at two ash levels i.e. 21% and 24% with same filler)

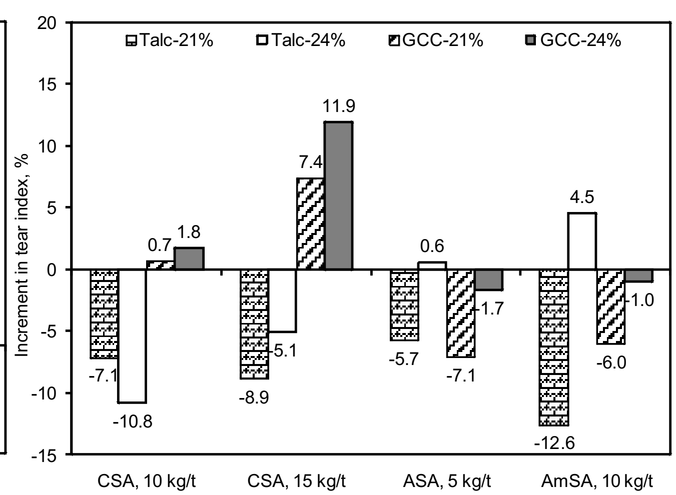

Figure 4: Increment in tear index of paper made from bleached wheat straw pulp with addition of different strength additives as compared to the references (5 kg/t of CSA at two ash levels i.e. 21% and 24% with same filler)

At 10 and 15 kg/t dosage of CSA in comparison to the first reference, the gain in ZDTS was more with talc than that with GCC filler. In case of talc, filler by increasing the dose of CSA up to 15 kg/t, the ZDTS of paper was comparable to that of reference. However at 24% ash level, 8.1% increase in ZDTS was observed with 10 kg/t dosage of CSA which slightly increased by increasing the dosage of CSA to 15 kg/t. In case of GCC filler, with CSA dosage of 10 and 15 kg/t, the ZDTS was increased by 1.6% and 2.8% respectively at ash level of 21%. At 24% ash level this gain was by 3.7 and 5.7% respectively.

In case of AmSA, the gain in ZDTS was more than that with CSA with talc filler. About 1.3 and 5% gain was observed at AmSA dosages of 5 and 10 kg/t in comparison to the first reference with talc filler at 21% ash while 11.7 and 15.8% gain was observed at 24% ash level at with 5 and 10 kg/t dosage of AmSA respectively. With GCC filler a very marginal gain in ZD was observed even at higher doses of AmSA (Figure 5).

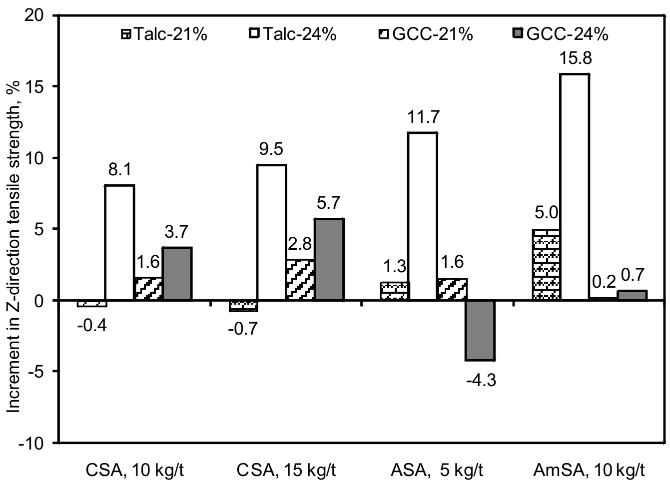

Figure 5: Increment in Z-direction tensile strength of paper made from bleached wheat straw pulp with addition of different strength additives as compared to the two references (5 kg/t of CSA at two ash levels i.e. 21% and 24% with same filler)

Conclusion

The retention of filler and the strength additive for a particular grade of pulp is important in paper making. The retention of talc filler was comparatively higher than that of GCC. The drop in strength properties of paper was more with GCC than that with talc filler; the former was having lower particle size distribution. The strength of paper decreased with increasing filler loading in paper with both talc and GCC fillers. However, this trend could be changed with the use of an appropriate dry strength additive. Under our experimental conditions, the ash in paper can easily be increased from 21 to 24% in case of both talc and GCC fillers without much affecting the paper strength. The selection of an appropriate strength additive is highly important when increase of filler in paper is desired. Amphoteric strength additive was more effective with talc filler than GCC. However the filler retention was comparatively more with cationic strength additive in case of both the fillers.

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