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REPORT

ON

Development of High Ash Paper to Reduce Fiber Input as well as Cost

Sponsored

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3	Project Team	:	1 Vipul S. Chauhan (PI) 2 Ashish Sharma 3 Shaveta Kakkar 4 Rita Tandon (CPPRI, Saharanpur) 5 R. Varadhan 6 N. K. Bhardwaj
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Contents

Nomenclature

AKD	Alkyl ketene dimer
APAM	Anionic polyacrylamide (High molecular weight)
AS	Amphoteric strength additive
BBS	Bagasse (Bleached)
BRC	Recycled (Bleached)
BWS	Wheat straw (Bleached)
CFA	Cationic fixing agent (Low molecular weight)
CIE	International Commision on Illumination (French: Commission Internationale de l'Eclairage)
CPAM	Cationic polyacrylamide (Medium to high molecular weight)
CS	Cationic strength additive
CSF	Canadian standard freeness
DS	Degree of substitution
FPAR	First pass ash retention
GCC	Ground calcium carbonate
ISO	International Standards Organization
L&W	Lorentzen & Wettre
MHB	Mixed hardwood blended with bamboo (Bleached)
MHW	Mixed hardwood (Bleached)
o.d.	Oven dry
^{o}SR	Schopper-Riegler number
PCC	Precipitated calcium carbonate
PS	Polymeric strength additive
Ref	Reference
Talc	Hydrated magnesium silicate
w/v	Weight by volume
ZDTS	Z-directional tensile strength

EXECUTIVE SUMMARY

The increasing cost of virgin pulp and the energy associated with its transformation to paper are familiar problems to the paper industry. The boom in hardwood utilization, the optimization of high-yield pulping processes, and the ongoing conversion to alkaline sizing are only a few examples of the many attempts made in recent years to make the production of paper more economical. A further example, and one that has proved particularly economical, is the replacement of pulp fibers with less expensive filler materials. Such high-filler content papers are commonly referred as "high ash paper". However, a major constraint in making high ash paper is the impairment of fiber-fiber bonding, and the resulting decrease in paper strength.

The incorporation of fillers into the papermaking process mainly adds positively to sheet formation, smoothness, brightness, opacity, dimensional stability and printing characteristics. In abroad, papermakers are producing fine paper with higher filler level (~ 20% or more) due to the availability of strong fiber. Still, they are continuously working to increase it further. The main reason behind it is to reduce papermaking cost. In India, the papermakers are not in a position to increase filler content beyond a certain limit (~15%) which is much lower as compared to filler content in paper manufactured abroad. The reasons could be the suitability of filler with wet-end chemicals (mainly dry & wet strength additives and retention aids) and fiber i.e. short hardwood fiber, agro-residues fiber and recycled fibers. The morphology and ionic behavior are also very important in fillers' selection. The fiber length of Indian raw material is comparatively lower, thus strength drop is higher with addition of filler.

Papermakers are also working on new developments on pre-treatment of filler to retain more filler in paper without adversely affecting strength properties. These methods may also be useful to increase filler in Indian fine papers without compromising paper strength.

To optimize above factors in selection of a suitable filler, a detailed study on Indian pulp furnishes was carried out using direct filler loading and loading of pre-treated filler in paper. This project was planned to study all above factors with five different bleached varieties of pulp furnishes used in India such as mixed hardwood blended with bamboo (MHB), mixed hardwood (MHW), wheat straw (BWS), bagasse (BBS) and recycled (BRC) pulp. Three types of commercially available fillers; talc, ground calcium carbonate (GCC) and precipitated calcium carbonate (PCC), were used to get the varying ash content in paper from 15 to 24%, with an interval of 3. Three dry strength additives, cationic, amphoteric and polymeric, were used at different dose levels in the wet-end of papermaking process. The cationic and amphoteric strength additives and retention aid polymers were also used for the pre-treatment of fillers. The pre-treated fillers were then loaded in the sheets at the fixed dose levels.

The pulp furnishes were evaluated to generate the data and understand their fiber morphology, charge, zeta potential and other characteristics. The fiber length of the BRC pulp was the

highest among all pulp furnishes. The anionicity of the BBS pulp was higher than other pulp furnishes.

The selection of dry strength additive for a particular filler is highly desired as it may affect the retention of filler and paper properties. The incorporation of filler in paper decreases the paper strength; it also depends upon type of filler. The use of extra dose of dry strength additives at the wet-end section of papermaking process was quite useful to increase the ash in paper. Overall 4-5% ash could be increased in different pulp furnishes using 10-15 kg/t dose of any of the strength additives. It was observed that with talc filler, polymeric strength additive was the most effective strength additive followed by amphoteric and cationic strength additives. The polymeric strength additive was not good with GCC filler as it had a negative impact on filler retention and paper strength. With PCC, polymeric strength additive reduced the filler retention, however, it provided higher paper strength compared to other strength additives.

The split addition of dry strength additive in filler and wet-end was congenial to the increasing ash in paper without adversely affecting the paper strength. Through loading of pre-treated filler, without use of extra dry strength additive, the ash in paper could be further increased by 2-3% without adversely affecting the paper strength and maintaining the optical properties of paper.

The project was originally planned for 18 months but due to shortage of pulp furnishes and difficulty in getting other required materials on time, it was delayed by 7 months.

BACKGROUND

Fillers are usually used in papermaking to provide cost and energy savings, and to improve optical properties, sheet formation, smoothness, printability, dimensional stability, and appearance of papers [1-6]. For many paper grades, fillers are the second most important material of paper stock, in terms of the amount added, and their consumption in papermaking. Fillers can generally be divided into two groups, inorganic and organic. The dominant fillers used in papermaking are inorganic fillers. Organic fillers are of two main types, hollow micro-spheres and porous fillers, and they are suitable only for special applications because of high price.

The conventional and frequently used inorganic fillers are kaolin clay, natural ground calcium carbonate, precipitated calcium carbonate, and talc. Another noticeable material is titanium dioxide; however, it is applied less often due to its high price. It is generally considered that the use of inorganic fillers, especially at high loading levels, has the following disadvantages or limitations:

- Conventional low-cost and high-performance calcium carbonate fillers are not suitable for use in wood-containing or rosin-sized papers due to pulp darkening at alkaline pH and dissolution of calcium carbonate below pH 7.
- Paper strength is inevitably reduced by replacement of the fibers by inorganic fillers, not only because there are less fibers in the sheet, which reduce 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 levels of inorganic fillers have negative effects on filler retention, resulting in higher solids content of the circulating system.
- Increased loading levels of inorganic fillers have 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.

In order to overcome or alleviate the above disadvantages or limitations, many methods have been proposed, among which filler modification for improving the use of inorganic fillers in papermaking has been a hot topic. Filler modification is of significant potential for the improvement of the use of inorganic fillers in papermaking, and it is highly favorable to the development of high filler technology [7-8].

The use of filler depends upon nature of fiber, wet-end process parameters/ conditions, wet-end chemicals and additives, and end-use of paper. 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. The boom in hardwood utilization, the optimization of high-yield pulping processes, and the ongoing conversion to alkaline sizing are only a few examples of the many attempts made in recent years to make the production of paper more economical. The high-filler content papers are commonly referred as "high ash paper". However, a major constraint in making high ash paper is the impairment of interfibrillar bonding, and the resulting decrease in paper strength [9].

In abroad, papermakers are producing fine paper with higher filler level (~20% or more) due to the availability of strong fiber. The filler loading levels for typical office and offset papers are up to 30% in Europe and up to 35% in North America [1]. Still, they are continuously working on the ways to increase it further. The core reason behind it is to reduce papermaking cost. In India, the papermakers are not in a position to increase filler content beyond a certain limit (~15% maximum) which is approximately half of the ash content in paper manufactured abroad. The reasons could be the suitability of filler with wet-end chemicals (mainly dry & wet strength additives and retention aids) and fiber i.e. short hardwood, agro-residues and recycled fibers. The morphology and ionic behavior are also very important in fillers' selection. The fiber length of Indian raw material is comparatively lower, thus strength drop is higher with addition of any filler.

The previously discussed new development methods for filler modification to retain more filler in paper without affecting strength properties have prominent perspective. These methods may also be useful to increase filler in Indian fine papers without compromising paper strength. To optimize above factors in selection of suitable filler along with the process for its use, a detailed study on major Indian bleached pulp furnishes such as mixed hardwood, mixed hardwood blended with bamboo, bagasse, wheat straw, and recycled pulps is required to increase ash content in paper and reduce cost without affecting strength properties of paper.

OBJECTIVE

- Optimization of suitable process to develop high ash paper without strength loss
  - Determination of physico-chemical properties of various fillers
  - Study the effect of various fillers on paper properties
  - Study on different process(es) and wet-end chemicals for increasing paper ash without affecting strength

SCOPE

1. Fillers: talc, GCC, PCC
2. Bleached pulp furnishes: Mixed hardwood blended with bamboo (MHB), mixed hardwood (MHW), wheat straw (BWS), bagasse (BBS), and recycled (BRC)
3. Varying ash content in paper such as 15% to 24% depending upon fiber furnish
4. AKD sizing at a fixed sizing level for all experiments
5. Retention aids: anionic and cationic
6. Different dry strength additives (cationic, amphoteric and polymeric)
7. Pre-treatment of fillers with different chemicals

EXPERIMENTAL

1. Materials

1.1 Pulp

Five different pulp furnishes collected from different pulp and paper mills in India have been used in this project. The bleached pulp furnishes were mixed hardwood (MHW), mixed hardwood blended with bamboo (80:20) (MHB), bagasse (BBS), wheat straw (BWS) and recycled (BRC).

1.2 Wet-end chemicals

a) Alkyl ketene dimer (AKD) having 17% solids content (w/v) was used at a fixed dose of 6 kg/t as an alkaline sizing agent to provide hydrophobicity to paper.

b) Cationic strength additive (CS) of 0.02-0.025 degree of substitution

c) Amphoteric strength additive (AS) of 0.03 degree of substitution

d) Non-ionic grafted/modified polymeric strength additive (PS) of natural gum (Galactose)

e) Low molecular weight polyamine, cationic fixing agent (CFA) was used at fixed dose of 200 g/t to provide some cationicity to the pulp stock.

f) Retention aids: a medium to high molecular weight cationic polyacrylamide (CPAM) and a high molecular weight anionic polyacrylamide (APAM)

1.3 Fillers

- Talc (hydrated magnesium silicate)
- GCC (ground calcium carbonate)
- PCC (precipitated calcium carbonate)

2. Methods/ procedures

2.1 Refining of pulp

The MHB and MHW pulps were refined to attain 30^0SR in PFI Mill (manufactured by HAMJERN MASKIN) following TAPPI Test Method T 248 sp-00. In all the experiments, the beaten pulp of 30^0 SR was used except some preliminary experiments for the comparison of ash content and FPAR at 30^0 and 40^0 SR levels in case of MHB pulp. The BBS, BWS and BRC pulps were used as such without refining.

2.2 Cooking of cationic, amphoteric and polymeric strength additives

Cationic and amphoteric strength additives were dispersed to 1% (w/v) slurry by mixing them with distilled water. The dispersed slurry was taken into a beaker and placed into water bath. The temperature was raised to gelatinize the slurry. Continuous mild stirring was given to the

slurry. The slurry was then cooked at 90^0C for about 30 minutes. It was then cooled at ambient temperature and was used in wet-end as a strength aid.

The grafted polymeric strength additive was dispersed to 1% (w/v) slurry by mixing it with distilled water. The dispersed slurry was heated up to 80-85^{o}C with mild continuous agitation. It was then cooled at ambient temperature and was used in wet-end as a strength aid.

2.3 Stock preparation

Different components (chemicals and additives) were added to the pulp slurry in the following order with continuous stirring:

a) Pulp (1% consistency)

b) CFA

c) Strength aid

d) AKD

e) Filler

f) Filtered water of pH 7.5 to make a pulp slurry of 0.3-0.4% consistency

g) Retention aid

2.4 Making of handsheets on sheet former

Handsheets of 70 g/m^2 were made on sheet former as per TAPPI Test Method T 272 sp-97.

2.5 Sheet pressing and drying

Sheets pressing and drying was done according to TAPPI Test Method T 218 sp-02.

2.6 Making of sheet on Buchner funnel

Buchner sheets were made for reflectance test following TAPPI Test Method T 218 sp-02.

2.7 Conditioning of handsheets

The conditioning of handsheets was done following TAPPI Test Method T 402 sp-98 at 23±1^{0}C and 50±2% RH (relative humidity).

2.8 Pre-treatment of fillers

The pre-treatment of different fillers such as GCC, PCC and talc was done with different strength additives and retention aid polymers. The process conditions for pre-treatment of filler (filler concentration, agitator speed, time, etc.) were selected based upon several experiments. Filler slurry at required concentration was stirred for five minutes at optimized revolutions according to the nature of the flocculant. Flocculant was added drop wise in the filler slurry for one minute with continuous stirring. Retention time of five minutes was given to the slurry for pre-treatment of filler. The slides were prepared at different concentrations to view the floc size

in Image analyser. Pre-treatment of filler depends on concentrations of filler slurry, charge density of flocculant and speed of mixer (shear force) during pre-treatment, which were optimized separately.

3. Analytical techniques

3.1 Moisture in pulp

Moisture content of pulp was determined as per TAPPI Test Method T 210 cm-86.

3.2 CSF of pulp

The extent of refining of pulp, CSF, was determined as per TAPPI Test Method T 227 om-99.

3.3 Characterization of filler

Fillers were characterized for optical properties (brightness, L*, a*, b*, etc.), particle size distribution, particle structure and chemical formula, moisture content, ionic behavior, charge demand, zeta potential, and the pH of the filler suspension.

Optical properties: Optical properties of fillers were determined as per TAPPI Test Method T 646 om-02. At first, a compact dice of filler having smooth surface was prepared in a small cylinder with the help of compression plate, plunger and arbor press. Optical properties were checked in Datacolor brightness tester as per the instruction manual.

Particle size distribution: Particle size distribution of filler was determined with MICROSCAN II (Quanta Chrome Corporation, USA). It utilizes soft X-ray to measure particle concentration in a sedimentation cell.

Particle Structure and Chemical Formula: The crystallographic structure of the fillers was determined by X-Ray Diffraction (D-Max IIIC from Rigaku, Japan) using Cu-Kα radiation. Chemical composition was determined using Energy Dispersive Spectrometer (TN-5500 from Tractor Northern); an attachment to Scanning Electron Microscope (JSM-840A from JEOL, Japan).

pH: Filler suspension (10% w/v) was filtered through a 300 micrometer screen and the pH of the filtrate was measured using pH meter.

Ionic Behavior and Charge Demand: 10 ml of 10% (w/v) filler slurry filtered through 200 micrometer screen was taken as the sample. The charge was measured on Mutek PCD 03 pH and the sample was titrated with cationic/ anionic polymer to neutralize the charge. The PCD 03 pH analyzed the colloidal dissolved charge in the form of streaming potential and gave the relative charge demand to neutralize the solution.

Zeta Potential: About 500 ml sample of 10% (w/v) filler was taken and mixed thoroughly before measurement. The zeta potential was measured using SZP 06. The SZP 06 gives the surface charge of materials.

3.4 Ionic behavior and charge demand of pulp slurry

The pulp slurry was filtered through 200 micrometer screen and 10 ml of the filtrate was taken as the sample. The charge was measured on Mutek PCD 03 pH Particle Charge Detector and the sample was titrated with cationic/ anionic polymer to neutralize the charge.

3.5 Zeta potential of pulp slurry

About 500 ml pulp slurry (0.33% consistency) was taken and mixed thoroughly before measurement. The zeta potential of the pulp slurry was measured using SZP 06.

3.6 Ash and FPAR in paper sheet

The ash content of the hand sheet was determined as per TAPPI Test Method T 211 om-93 at 525^0C. The ash content and first pass ash retention were calculated using the following formula:

$$\text{Ash content, \%} = \frac{\text{(Crucible + ash) weight – Crucible weight}}{\text{Handsheet weight}} * 100$$

$$\text{First pass ash retention, \%} = \frac{\text{Handsheet ash, \%}}{\text{Buchner sheet ash, \%}} * 100$$

3.7 Optical properties of handsheets

The optical properties of paper handsheets were measured with the brightness tester (Datacolor Spectraflash 300) using following test methods.

- Brightness of handsheets was determined as per TAPPI Test Method T 525 om-02.
- Opacity and scattering coefficient were determined as per TAPPI Test Method T 519 om-02.
- CIE whiteness was determined as per TAPPI Test Method T 560 pm-96.

3.8 Physical properties of handsheets

The physical strength properties and surface characteristics of paper handsheets were determined as per following standards.

Property	Standard procedure	Instrument
Thickness	TAPPI T 411 om-97	L&W Micrometer Version C
Breaking length	TAPPI T 494 om-01	L&W Tensile Tester (SE060)
Burst index	TAPPI T 403 om-97	L&W Bursting strength Tester (SE 180)
Tearing index	TAPPI T 414 om-98	L&W Tearing Tester (SE 009)
Bending stiffness	TAPPI T 535 om-96	L&W Bending Tester (SE 160)
Air permeance	TAPPI T 460 om-02	L&W Air Permeance Tester (SE 166)
Bendtsen roughness	ISO 8791-2	L&W Bendtsen Tester (SE 164)
ZD tensile strength	TAPPI T 541 om-99	L&W ZD Tensile Tester (SE 155)
Wax pick number	TAPPI T 459 om-99	Wax sticks

CHAPTER – 1

Bleached Mixed Hardwood Blended with Bamboo (MHB) Pulp

RESULTS & DISCUSSION

Two different approaches were followed to increase the ash in paper viz., 1) addition of filler directly into pulp stock along with strength additives, and 2) pre-treatment of fillers using differently charged polymers/ strength additives and then addition into pulp stock. The first one has been described here. All three fillers were added to attain different ash levels viz. 15, 18, 21, 24% approximately and their addition levels were kept constant for attaining these ash levels. Strength additives were added at different doses.

The characterization of wet-end chemicals and fillers were made first to understand the wet-end chemistry and chemical behavior towards papermaking process and paper properties.

1. Characterization of wet-end chemicals

1.1. Fillers

1.1.1. Optical properties

The optical properties of precipitated calcium carbonate (PCC) is highest followed by ground calcium carbonate (GCC) and talc. The difference in brightness of PCC and talc, and PCC and GCC was around 6 and 1.8% respectively (Table 1).

1.1.2 Particle size distribution

GCC was finest among all the fillers. The fraction below 2.2 micron particle size in case of GCC, talc, and PCC was 78.4, 20.9, and 19.0% respectively. It was implicit that talc had almost similar particle size to that of PCC. But the particles finer than 4 micron were different. These were 76% for PCC against 47.3% in case of talc. The similar trend was also seen for the particles finer than 7 and 12 microns. It showed that the average particle size of PCC was finer than that of talc (Table 2).

1.1.3 Crystalline structure and chemical formula

From the XRD analysis of the fillers it was observed that PCC had sclanohedral structure whereas both GCC and talc were monoclinic (Table 3). EDS analysis was carried out to know the chemical composition of fillers that indicated that both the carbonate fillers (GCC and PCC) have same chemical composition i.e. calcium oxide (CaO, 100%). The chemical composition of talc was magnesium oxide (MgO, 24.31%) and silica (SiO_2, 74.69%).

1.1.4 Ionic behavior

GCC and PCC were cationic in nature, whereas talc was anionic. From the analysis of dissolved and colloidal charge, and zeta potential it was evident that the colloidal charge and charge demand of both GCC and PCC were almost comparable. Zeta potential of GCC was more cationic than that of PCC (Table 4).

1.2 Other wet-end chemicals

The ionic behavior of wet-end chemicals was measured to understand the chemistry. As expected, the dissolved and colloidal charge of refined pulp was anionic. The charge of cationic fixing agent (CFA), cationic strength additive (CS), amphoteric strength additive (AS), alkyl ketene dimer (AKD), and cationic polyacrylmide flocculant (CPAM) was cationic whereas polymeric strength additive (PS) and anionic polyacrylmide flocculant (APAM) were anionic. The AKD was highly acidic in nature with a pH of 3.3 (Table 5).

2. Effect of direct filler loading

2.1. Effect of refining on ash and FPAR

As the retention of fillers was very crucial at some degree of refining of pulp, the effect of refining on ash content and first pass ash retention (FPAR) of fillers was seen without addition of other wet-end chemicals. The ash content and FPAR of fillers increase to some extent with increasing refining of pulp. The trend was dependent on nature of filler. FPAR increased with the increase in pulp slowness (^{0}SR) i.e. decreasing freeness. At different addition levels of fillers, the effect of pulp slowness was different. Overall increase in FPAR with an increase in ^{0}SR from 30 to 40 was around 4-6, 2-4 and 6-7% with talc, GCC and PCC respectively. The FPAR was lowest in case of GCC probably due to its lower particle size (Table 6).

2.2. Effect of wet-end chemicals (mainly retention aid) on ash and FPAR

It was seen that the ash content and FPAR were different for three fillers at same filler addition without addition of retention aids and other wet-end chemicals. It was due to their particle size distribution, shape and chemical nature and surface charge. The FPAR was significantly high even without addition of wet-end chemicals and with the addition of wet-end chemicals the same increased further for both talc and PCC (Table 7).

2.3. Effect of cationic strength additive and talc filler on paper

As expected with increasing dose of talc, the strength properties of paper decreased whereas optical properties increased at all doses of cationic strength additive (CS) (Table 8-10). The zeta potential of pulp slurries increased with increasing talc due to anionic nature of the filler. The zeta potential of pulp slurries decreased on increasing dose of CS.

2.3.1. At 280 kg/t of talc

At 280 kg/t addition of talc, the ash content in sheets was approximately 15% at all doses of CS. There was an increase in burst index and breaking length of paper with increase in CS dose. Tear index and opacity were almost comparable at all doses of CS (Figure 1). Double fold were 13 to 17 and 22 with 5, 10, and 15 kg/t dose of CS respectively.

2.3.2. At 340 kg/t of talc

At 340 kg/t addition of talc, the ash in sheets remained unaltered (17.5%) irrespective of different doses of CS. At 10 kg/t dose of CS, all strength properties were almost comparable with those of reference (15% ash with 5 kg/t dose of CS). From figure 2 it was seen for talc as filler that ash in paper can be increased from 15 to 17.5% with 10 kg/t dose of CS without affecting the strength properties. The opacity also increased by 1% due to increase in ash from 15 to 17.5%.

2.3.3. At 400 kg/t of talc

At 400 kg/t addition of talc, the ash in sheets was approximately 20% at all doses of CS. All strength properties of paper at 20% ash level were lower than that of reference at 5 and 10 kg/t dose of CS, but at 15 kg/t, breaking length and ZDTS were comparable whereas burst index and tear index were lower 5 and 4% respectively as compared with reference (Figure 3).

2.3.4. At 470 kg/t of talc

Further increasing ash content to 23% with 470 kg/t dose of talc was detrimental towards the strength properties even at higher dose of CS (Figure 4).

It can be concluded that the ash can be increased from 15 to 17.5% with 10 kg/t dose of CS and to 20% with 15 kg/t dose of CS without any adverse impact on strength properties. It also improved the optical properties of paper including opacity and scattering coefficient.

2.4. Effect of amphoteric strength additive and talc filler on paper

Similar to the results in case of CS, the strength properties decreased with increase in ash in paper. Optical properties increased at all doses of amphoteric strength additive (AS) (Table 11-13). The zeta potential of pulp slurries increased with increase in dose of talc. Due to cationic nature of AS, the zeta potential of pulp slurries decreased with increase of AS dose.

2.4.1. At 280 kg/t of talc

At 280 kg/t addition of talc, the ash in sheets was approximately 15% at all doses of AS. There was an increase in all strength properties with increase in dose of AS. Even at 5 kg/t dose of AS, strength properties were higher than those of reference (15% ash with 5 kg/t dose of CS). With further increase in dose of AS, all strength properties increased. AS seemed to be highly effective on strength properties when talc was used as filler (Figure 5). Bulk of paper was almost comparable at all ash levels (Table 11-13).

2.4.2 At 340 kg/t of talc

At 340 kg/t addition of talc, the ash in sheets was approximately 18% at all doses of AS. There was 0.5% increase in ash as compared to that in case of CS at same talc addition level which indicated that AS could increase the ash in paper to some extent. The breaking length and burst index were higher than those of reference but tear index slightly decreased. ZDTS was

comparable to reference at 15 kg/t dose of AS. From Figure 6 it was seen that in case of talc, ash content in paper could be increased from 15 to 18% with 10 kg/t of AS with increased breaking length and burst index. The gain in opacity was around 1%.

2.4.3. At 400 kg/t of talc

At 400 kg/t addition of talc, the ash in sheets was approximately 21% at all doses of AS; approximately 1% higher than that with CS at same talc addition. At 10 and 15 kg/t dose of AS, the breaking length and burst index increased but tear index and ZDTS decreased. The decrease in tear index and ZDTS at 15 kg/t dose of AS was around 8 and 2.8% respectively as compared to reference (Figure 7).

2.4.4. At 470 kg/t of talc

At 470 kg/t addition of talc, the ash in paper sheets at all doses of AS was approximately 24.5%; approximately 1.5% higher than that with CS at same talc level. The breaking length and burst index were comparable at 15 kg/t dose of AS. The tear index and ZDTS decreased by 15 and 3.6% respectively as compared to those of reference (Figure 8). Decrease in refining might increase the tear index without affecting breaking length and burst index of paper too much. There was a need to examine this aspect.

It was concluded that the ash content of paper could be increased from 15 to 18% with 10-15 kg/t dose of AS. It also improved optical properties of paper including opacity and scattering coefficient.

2.5. Effect of polymeric strength additive on paper properties with the talc as filler

The lower dose of PS was not effective as compared to CS and AS with respect to ash in paper, so it was decided to have higher dose of PS on paper properties. With increased dose of PS, the FPAR and strength properties of paper increased at all doses of PS. Due to anionic nature of PS, charge demand of pulp slurries increased with increase of PS dose. (Table 16-19, Figure 9-12).

2.5.1. At 280 kg/t of talc

At 280 kg/t addition of talc, the ash in sheets was 15.9, 15.9, 16.3 and 17.2% at 4, 6, 8 and 10 kg/t dose of PS; 1-2% higher than that of reference (15% ash with 5 kg/t dose of CS) at same talc addition. Breaking length, burst index and ZD tensile strength (ZDTS) were also increased even at increased ash levels. Tear index and opacity were almost comparable at all PS doses (Figure 9).

2.5.2. At 340 kg/t of talc

Similar to the above case, with 340 kg/t addition of talc, the ash with the addition of was 18.2 to 19.3%; around 1.8% higher than that of reference at same talc addition. It showed that PS moderately increased ash in paper when talc was used as filler. The breaking length and burst

index were comparable at 6 kg/t and increased at higher dose of PS but tear index decreased by around 8.5% even at the highest dose of PS (10 kg/t). ZDTS and opacity were almost comparable to reference (Figure 10).

2.5.3. At 400 kg/t of talc

Similar to the above two cases, 400 kg/t addition of talc increased the ash in paper from 20.2 to 22.3% with the addition of PS; around 2% higher than that of reference. With 8 kg/t dose of PS, breaking length, burst index and ZDTS were almost comparable to those of reference but tear index decreased by around 14%. Gain in opacity was around 1.5% (Figure 11).

2.5.4. At 470 kg/t of talc

In case of 470 kg/t addition of talc the ash in paper with PS addition increased around 2% i.e. from 23.2 to 25.3%. At this ash level, all strength properties decreased even at highest dose of PS. Gain in opacity was around 2% (Figure 12).

It could be concluded that the ash in paper could be increased from 15 to 21% with some compromise on tear index.

2.6. Effect of cationic strength additive and GCC filler on paper

The strength properties decreased with increase in ash in paper, whereas optical properties increased at all doses of CS. The zeta potential and charge demand of pulp slurries decreased with increase in dose of GCC. Due to cationic nature of CS, the zeta potential and charge demand decreased with the increased dose of CS. The FPAR with GCC filler (~55%) was comparatively lower than that with talc (~70%) when CS was used as strength aid. The bulk of the paper made with GCC was slightly higher than that with talc (Table 20-22).

2.6.1. At 400 kg/t of GCC

At 400 kg/t addition of GCC, the ash in paper was approximately 15% at all doses of CS. There was an increase in all the strength properties with increase in CS dose. Opacity was almost comparable at all CS doses (Figure 13). Double fold of paper also increased with increase in dose of CS (Table 20-22).

2.6.2. At 480 kg/t of GCC

At 480 kg/t addition of GCC, the ash in paper was approximately 18% at all doses of CS. With 10 kg/t dose of CS, the strength properties were comparable to those of reference (15% ash with 5 kg/t dose of CS), though there was little increase in burst index and ZDTS as compared with reference (Figure 14).

2.6.3. At 560 kg/t of GCC

At 560 kg/t addition of GCC, the ash in paper varied from 19.4 to 20.6% with the increase in dose of CS. The strength properties of paper except tear index were comparable at 10 kg/t dose of CS. The drop in tear index was around 4%. Gain in opacity was around 1.3% (Figure 15).

2.6.4. At 670 kg/t of GCC

At 670 kg/t addition of GCC, the ash in paper was 21.1, 21.9 and 22.3% at 5, 10 and 15 kg/t dose of CS respectively. It showed that the ash in paper could be increased about 1% with higher dose of CS from 5 to 15 kg/t. All strength properties except burst index decrease as compared with reference (Figure 16).

It could be concluded that the ash in paper could be increased from 15 to 18% with GCC as filler with the addition of 10-15 kg/t dose of CS.

2.7. Effect of amphoteric strength additive and GCC filler on paper

The strength properties decreased but optical properties increased with the increase in ash in paper at all doses of AS. The zeta potential and charge demand of pulp slurries decreased with increase in dose of GCC. The bulk of paper made with GCC was slightly higher than that with talc (Table 23-25).

2.7.1. At 400 kg/t of GCC

At 400 kg/t addition of GCC, the ash in paper increased from 15.4 to 16.1% with 15 kg/t of CS; around 0.7% increase as compared with reference (15% ash with 5 kg/t dose of CS). There was an increase in all strength properties with increase in AS dose. At 10-15 kg/t dose of AS, all strength properties were higher than those of reference. Opacity was almost comparable to reference (Figure 17).

2.7.2. At 480 kg/t of GCC

At 480 kg/t addition of GCC, the ash in paper was approximately 18.5% at all AS doses. At 10 kg/t doagse of AS, burst index and breaking length were higher whereas tear index and ZDTS were lower than those of reference. Further increase in dose of AS increased all strength properties. At this dose level, the drop in tear index and ZDTS was around 4.4 and 2.4% respectively than that of reference. The gain in opacity was around 0.8% (Figure 18).

2.7.3. At 560 kg/t of GCC

At 560 kg/t addition of GCC, the ash in paper was around 21% at all doses of AS. At 15 kg/t dose of AS, burst index and breaking length were comparable to those of reference but tear index and ZDTS decreased by around 11 and 5% respectively. Gain in opacity was around 1.5% (Figure 19).

2.7.4. At 670 kg/t of GCC

At 670 kg/t addition of GCC, the ash in paper was around 23% at all doses of AS; 1% higher than that of reference. At this ash level the trend of strength properties was similar to those with 21% ash in paper. Except burst index all strength properties were on the lower side (Figure 20).

It can be concluded that the ash in paper can be increased from 15 to 18% with 10-15 kg/t dose of AS.

2.8. Effect of polymeric strength additive and GCC filler on paper

It was seen that when PS was used with GCC as filler, the retention of ash decreased. Table 26 showed that with the increase in dose of PS from 4 to 10 kg/t decreased the FPAR and ash in paper decreased. It was observed that the negative effect on ash retention was higher at higher filler addition levels. At 670 kg/t of GCC addition, the ash in paper was around 21% with 4 and 6 kg/t dose of PS whereas it was around 17-18% with 8 and 10 kg/t dose of PS. The experiments were confined only on two dose levels i.e. 4 and 6 kg/t. At higher ash levels, the increase in breaking length was higher with PS as compared to CS though the tear index was comparatively lower with PS (Table 26). Due to anionic nature of PS, charge demand increased with increase in dose of PS (Table 27-28).

2.8.1. At 400 kg/t of GCC

At 400 kg/t addition of GCC, the ash in paper decreased from 15.4 to 14.5 and 14.8% at 4 and 6 kg/t dose of PS respectively. The breaking length and burst index were higher than that of reference (15% ash with 5 kg/t dose of CS) but tear index and ZDTS were lower by around 6 and 4% respectively. Opacity was almost comparable to reference (Figure 21).

2.8.2. At 480 kg/t of GCC

At 480 kg/t addition of GCC, the ash in paper decreased from 18 to 16.5 and 16.8% at 4 and 6 kg/t dose of PS respectively. Similar to the above cases, in this case also breaking length and burst index were higher than that of reference but both tear index and ZDTS were lower by around 8%. Gain in opacity was around 1% (Figure 22).

2.8.3. At 560 and 670 kg/t of GCC

Further increase in addition level of GCC to 560 and 670 kg/t showed a negative effect on tear index and ZDTS in both the cases, whereas breaking length and burst index were almost comparable (Figure 23-24).

It could be concluded that the PS was not effective on the retention of GCC. Strength properties were also not much improved with PS as compared to CS and AS.

2.9. Effect of cationic strength additive and PCC filler on paper

At all doses of CS with increase in dose of PCC, the strength properties decreased whereas optical properties increased (Table 29-31). The decrease in strength properties in case of PCC was higher than that in case of talc. It might be due to the reason that PCC has a higher percentage of finer particles i.e. higher surface area. The bulk of paper increased with the use of PCC as compared to talc. Optical properties viz. brightness, whiteness, opacity, and scattering coefficient increased significantly with PCC as compared to those with talc.

2.9.1. At 300 kg/t of PCC

At 300 kg/t addition of PCC, the ash in paper at all doses of CS was approximately 15%. There was an increase in all strength properties with increase of CS dose (Figure 25).

2.9.2. At 360 kg/t of PCC

At 360 kg/t addition of PCC, the ash in paper was approximately 18% at all doses of CS. At 10-15 kg/t dose of CS, almost all strength properties were either comparable or higher as compared with those of reference (15% ash with 5 kg/t dose of CS). From Figure 26 it can be observed that in case of PCC, ash content in paper can be increased from 15 to 18% with 10-15 kg/t dose of CS without affecting the strength properties. The opacity increased by ~2% due to the increase in ash from 15 to 18%.

2.9.3. At 440 kg/t of PCC

At 440 kg/t addition of PCC, the ash in paper was approximately 20.5% at all doses of CS. There was an increase in breaking length with comparable ZDTS at 10-15 kg/t dose of CS whereas both burst index and tear index decreased by around 5% as compared to those of reference (Figure 27).

2.9.4. At 520 kg/t of PCC

Further increase addition of PCC to 520 kg/t enhanced the ash in paper to 23%. Here also, the breaking length and ZDTS at 15 kg/t dose of CS were comparable whereas both burst index and tear index decreased by around 7 and 8% respectively as compared to those of reference (Figure 28).

It could be concluded that the ash in paper could be increased from 15 to 18% with PCC as filler with 10-15 kg/t dose of CS without affecting strength properties. It also improved optical properties of paper including opacity and scattering coefficient.

2.10. Effect of amphoteric strength additive PCC filler on paper

Similar to the results with CS, the strength properties decreased with increase in ash in paper whereas optical properties increased at all doses of AS (Table 32-34).

2.10.1. At 300 kg/t of PCC

At 300 kg/t addition of PCC, the ash in paper was approximately 15.5-16.5% at all doses of AS. Ash content increased with increase of AS dose. There was an increase in all the strength properties with increase in AS dose. Even at 5 kg/t dose of AS, all strength properties except tear index were higher than those of reference (15% ash with 5 kg/t dose of CS) (Figure 29).

2.10.2. At 360 kg/t of PCC

At 360 kg/t addition of PCC, the ash in paper was approximately 18% at all doses of AS. The breaking length, burst index, and ZDTS were higher than those of reference but tear index dropped by around 7% at 10 kg/t dose of AS. At 15 kg/t dose of AS, the drop in tear index reduced to 2% as compared to that of reference. It was observed that in case of PCC, ash in paper can be increased from 15 to 18% with 10-15 kg/t of AS without affecting the strength properties with 1% gain in opacity (Table 30).

2.10.3. At 440 kg/t of PCC

At 440 kg/t addition of PCC, the ash in paper was approximately 21% at all doses of AS. Except tear index, all strength properties of paper at this ash level with 10-15 kg/t dose of AS were higher than those of reference. The drop in tear index was around 7%. Hence, ash in paper could be increased from 15 to 21% with 15 kg/t dose of AS with a little compromise in tear index (Figure 31). By reducing the degree of refining tear index may be compensated.

2.10.4. At 520 kg/t of PCC

At 520 kg/t addition of PCC, the ash in paper was approximately 23.5% at all doses of AS. With the use of 15 kg/t dose of AS, the breaking length, burst index, and ZDTS were comparable to those of reference even at this high ash level except the drop in tear index which was around by 9% (Figure 32).

It could be concluded that the ash could be increased from 15 to 18% with 10 kg/t dose of AS and to 21% with 15 kg/t dose of AS without affecting strength properties. A slight decrease in refining would improve the tear index.

2.11. Effect of polymeric strength additive and PCC filler on paper

The anionic zeta potential and cationic charge demand of pulp slurries decreased with the increase in dose of PCC. Due to anionic nature of polymeric strength additive (PS), the zeta potential and charge demand increase with its increased dose (Table 35-37).

2.11.1. At 300 kg/t of PCC

At 300 kg/t addition of PCC, the ash in paper slightly decreased with increase in PS dose. Similarly at 15% ash, FPAR decreased from 65.0% (reference) to 61.4% with 10 kg/t dose of PS (Table 36). The drop in ash was from 15.1 to 14.2% with increase in dose of PS from 6 to 10

kg/t. All strength properties were higher at all doses of PS as compared with reference (15% ash with 5 kg/t dose of CS) which might partly be due to same or lower ash in paper (Figure 33).

2.11.2. At 360 kg/t of PCC

At 360 kg/t addition of PCC, ash in paper and FPAR decreased with increase in dose of PS. The ash reduced from 18.2% (reference with 5 kg/t dose of CS) to 17.1 and 16.1% with 6 and 10 kg/t dose of PS respectively. In this case also, all strength properties except tear index were higher than those of reference. The strength properties of paper increased with increase in dose of PS but at reduced ash content (Figure 34).

2.11.3. At 440 kg/t of PCC

At 440 kg/t addition of PCC also, ash in paper and FPAR decreased with increase in dose of PS. The ash reduced from 20.6 (reference with 5 kg/t dose of CS) to 19.3 and 17.8% with 6 and 10 kg/t dose of PS respectively. At 6 kg/t dose of PS, the burst index, breaking length and ZDTS were higher but tear index was lower by around 6.5% than that of reference (Figure 35).

2.11.4. At 520 kg/t of PCC

Similar to previous cases, at 520 kg/t addition of PCC also, ash in paper and FPAR decreased with increase in dose of PS. The ash reduced from 23.7 (reference with 5 kg/t dose of CS) to 21.8 and 20.8% with 6 and 10 kg/t dose of PS respectively. At this ash level with 10 kg/t dose of PS, the breaking length, burst index and ZDTS were higher than those of reference but tear index was lower by around 6% (Figure 36).

It could be concluded that the ash in paper could be increased from 15 to 18 and 21% with 6 and 8 kg/t dose of PS respectively without affecting strength properties. The slight drop in tear index can be compensated with reduced refining of pulp.

Table 1: Optical properties of fillers

Parameter	Talc	GCC	PCC
ISO brightness, %	89.7	94.0	95.8
CIE whiteness	83.5	93.0	94.8
Yellowness	3.33	0.46	0.55
L*	96.4	97.6	98.4
a*	0.14	0.03	0.07
b*	1.70	0.24	0.27

Table 2: Particle size distribution of fillers

Particle size	Talc, %	GCC, %	PCC, %
< 12.0 µm	89.6	-	96.0
< 7.0 µm	75.2	99.0	92.8
< 4.0 µm	47.3	93.9	76.0
< 2.2 µm	20.9	78.4	19.0
< 1.91 µm	19.3	67.0	15.8
< 1.00 µm	12.3	47.8	7.9
< 0.71 µm	7.0	37.8	5.6
< 0.59 µm	5.9	30.6	5.2

Table 3: XRD and EDS analysis of fillers

Filler	XRD analysis		EDS analysis
	Crystalline structure	Chemical formula	Compound, %
Talc	Monoclinic	$3MgO.4SiO_2.H_2O$	MgO (24.31), SiO_2 (74.69)
GCC	Monoclinic	$CaCO_3$	CaO (100)
PCC	Scalenohedral	$CaCO_3$	CaO (100)

Table 4: Characterization of fillers*

Filler	pH	Streaming potential, mV	Charge demand, µeq/L	Zeta potential, mV
Talc	10.3	- 370	172 (cationic)	- 267
GCC	8.6	+ 257	650 (anionic)	+ 401
PCC	9.7	+ 262	694 (anionic)	+159

** Filler concentration: 10% w/v*

Table 5: Characterization of wet-end chemicals*

Filler	pH	Viscosity, cp (100 rpm, spindle 2, 25^{o}C)	Streaming potential, mV	Charge demand, µeq/L
Beaten pulp	8.2	-	-248	9.8
CFA	4.3**	11.1**$^{\#}$	+760	18000
CS	6.4	31	+135	1655
AS	7.8	18	+215	2688
PS	6.4	103	-670	343
AKD	3.3	65.2	+54	2354
CPAM	3.8**	43**	+1038	13978
APAM	7.1**	39**	-1800	8820
Process water	7.7	-	-333	2.8

** 1% w/v*
*** 0.1% w/v*
 # Spindle 1

Table 6: Effect of pulp refining on ash content and FPAR of paper handsheets at 30 and 40° SR

Filler addition, kg/t pulp	Ash, %		FPAR, %	
	30° SR	40° SR	30° SR	40° SR
Talc				
100	5.6	6.1	61.6	67.1
200	10.2	11.3	61.2	67.8
300	14.5	15.7	62.8	68.0
400	18.5	19.6	64.8	68.6
500	22.0	23.5	66.0	70.5
GCC				
400	6.5	6.7	22.8	23.5
600	11.5	12.9	30.7	34.4
800	14.5	15.8	32.6	35.6
980	17.0	18.1	34.3	36.6
1350	22.2	24.2	38.6	42.1
PCC				
110	6.3	6.9	63.6	69.6
210	10.6	11.8	61.1	68.0
330	15.2	17.0	61.3	68.5
440	18.6	20.5	60.9	67.1
600	22.9	25.6	61.1	68.3

Note: Without addition of other wet-end chemicals

Table 7: Effect of wet-end chemicals on Ash and FPAR with different fillers at 30° SR

Filler addition, kg/t pulp	Without wet-end chemicals		With wet-end chemicals	
	Ash, %	FPAR, %	Ash, %	FPAR, %
Talc[1]				
280	13.6	62.4	15.0	68.6
340	16.1	63.6	17.5	69.0
400	18.5	64.8	20.2	70.6
470	21.1	65.7	23.2	72.6
PCC[2]				
300	14.0	61.2	15.5	65.0
360	16.3	61.2	18.2	68.8
440	18.6	60.9	20.6	67.4
520	20.8	61.0	23.7	69.3

Sequence followed with wet-end chemicals:

1. *Pulp + CFA, 200 g/t + CS, 5 kg/t + AKD + Talc → Dilution to 0.33% cy + CPAM, 200 g/t*
2. *Pulp + CFA, 200 g/t + CS, 5 kg/t + AKD + PCC → Dilution to 0.33% cy + APAM, 80 g/t*

Table 8: Properties of MHB pulp with talc and cationic strength additive at 5 kg/t

Talc addition, %	Blank*	28	34	40	47
Retained ash, %	0.5	15.0	17.5	20.2	23.2
FPAR, %	-	68.6	69.0	70.6	72.6
CSF, ml	515	460	480	490	505
Streaming potential, mV	-248	-256	-225	-200	-217
Charge demand, µeq/L	9.8	7.9	8.5	8.8	9.0
Zeta potential, mV	-29.8	-18.8	-18.8	-19.0	-19.7
Conductivity, mS	0.491	0.428	0.449	0.452	0.466
Bulk, cc/g	1.34	1.31	1.32	1.29	1.28
Breaking length, m	4804	3732	3651	3487	3212
Burst index, kN/g	3.30	2.48	2.23	2.14	1.95
Tear index, $mN.m^2/g$	7.84	6.49	6.27	5.94	5.52
Double fold, no.	26	13	11	11	10
ZD tensile strength, kPa	661	676	643	624	595
Bending stiffness, mN.m	0.290	0.224	0.216	0.188	0.166
Air permeance, Gurley s	9.4	8.7	8.6	7.6	7.6
Bendtsen roughness, mL/min	121	192	168	159	159
Brightness, %ISO	83.0	83.3	83.4	83.6	83.7
Opacity, %ISO	78.4	79.6	80.4	81.1	82.2
Scattering coefficient, m^2/kg	34.6	36.4	37.7	38.9	40.6
CIE whiteness	69.4	70.4	70.9	71.0	71.4
Yellowness	7.84	7.29	7.25	7.03	7.00
L*	93.4	95.2	95.2	95.1	95.3
a*	-0.10	-0.08	-0.10	-0.08	-0.12
b*	4.20	3.88	3.87	3.74	3.75

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 5 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Blank: beaten pulp to 30^0 SR without addition of wet-end chemicals*

Table 9: Properties of MHB pulp with talc and cationic strength additive at 10 kg/t

Talc addition, %	Reference*	28	34	40	47
Retained ash, %	15.0	15.4	17.6	20.5	22.7
FPAR, %	68.6	70.4	69.4	71.8	71.0
CSF, ml	460	465	480	495	510
Streaming potential, mV	-256	-130	-170	-167	-147
Charge demand, µeq/L	5.0	6.7	7.2	7.6	8.1
Zeta potential, mV	-18.8	-15.0	-15.5	-16.0	-17.5
Conductivity, mS	0.428	0.550	0.461	0.466	0.446
Bulk, cc/g	1.31	1.33	1.28	1.30	1.27
Breaking length, m	3732	3910	3805	3691	3421
Burst index, kN/g	2.48	2.60	2.55	2.32	1.98
Tear index, $mN.m^2/g$	6.49	6.51	6.36	6.17	5.87
Double fold, no.	13	17	14	12	11
ZD tensile strength, kPa	676	682	655	640	636
Bending stiffness, mN.m	0.224	0.236	0.196	0.178	0.166
Air permeance, Gurley s	8.7	8.8	8.6	8.6	7.6
Bendtsen roughness, mL/min	192	169	150	156	152
Brightness, %ISO	83.3	83.0	83.2	83.6	83.5
Opacity, %ISO	79.6	80.1	80.6	81.2	82.2
Scattering coefficient, m^2/kg	36.4	36.5	37.8	39.3	41.0
CIE whiteness	70.4	70.0	70.6	71.2	71.1
Yellowness	7.29	7.45	7.23	6.96	6.91
L*	95.2	95.2	95.2	95.3	95.1
a*	-0.08	-0.07	-0.05	-0.11	-0.07
b*	3.88	3.97	3.84	3.73	3.67

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 10 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHB with talc and CS, 5 kg/t at 15% ash level*

Table 10: Properties of MHB pulp with talc and cationic strength additive at 15 kg/t

Talc addition, %	Reference*	28	34	40	47
Retained ash, %	15.0	15.2	17.6	19.9	22.7
FPAR, %	68.6	69.5	69.4	69.7	71.0
CSF, ml	460	475	490	500	510
Streaming potential, mV	-256	-160	-175	-190	-205
Charge demand, µeq/L	5.0	5.0	6.2	6.4	7.9
Zeta potential, mV	-18.8	-13.0	-12.8	-13.8	-15.0
Conductivity, mS	0.428	0.458	0.460	0.464	0.468
Bulk, cc/g	1.31	1.31	1.32	1.30	1.30
Breaking length, m	3732	4173	4053	3846	3524
Burst index, kN/g	2.48	2.72	2.68	2.35	2.15
Tear index, $mN.m^2/g$	6.49	6.55	6.43	6.24	6.07
Double fold, no.	13	22	17	12	12
ZD tensile strength, kPa	676	692	681	675	650
Bending stiffness, mN.m	0.224	0.230	0.206	0.204	0.186
Air permeance, Gurley s	8.7	8.0	7.8	7.7	7.7
Bendtsen roughness, mL/min	192	166	164	169	158
Brightness, %ISO	83.3	82.6	83.5	83.5	83.6
Opacity, %ISO	79.6	80.1	81.1	81.9	82.3
Scattering coefficient, m^2/kg	36.4	36.9	38.9	40.2	41.6
CIE whiteness	70.4	70.2	70.4	71.0	71.0
Yellowness	7.29	7.26	7.27	7.08	7.09
L*	95.2	95.0	95.2	95.2	95.2
a*	-0.08	-0.10	-0.09	-0.10	-0.10
b*	3.88	3.87	3.88	3.78	3.79

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 15 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHB with talc and CS, 5 kg/t at 15% ash level*

Table 11: Properties of MHB pulp with talc and amphoteric strength additive at 5 kg/t

Talc addition, %	Reference*	28	34	40	47
Retained ash, %	15.0	15.2	18.3	20.8	24.0
FPAR, %	68.6	69.5	72.1	72.8	75.1
CSF, ml	460	515	525	530	575
Streaming potential, mV	-256	-193	-171	-188	-216
Charge demand, µeq/L	5.0	4.9	5.2	5.6	6.7
Zeta potential, mV	-18.8	-11.3	-11.8	-12.3	-13.9
Conductivity, mS	0.428	0.484	0.495	0.487	0.477
Bulk, cc/g	1.31	1.33	1.29	1.29	1.28
Breaking length, m	3732	3870	3762	3622	3479
Burst index, kN/g	2.48	2.56	2.42	2.23	2.02
Tear index, $mN.m^2/g$	6.49	6.56	5.93	5.49	5.17
Double fold, no.	13	13	11	13	10
ZD tensile strength, kPa	676	667	648	621	614
Bending stiffness, mN.m	0.224	0.222	0.208	0.184	0.178
Air permeance, Gurley s	8.7	9.0	8.2	8.0	7.8
Bendtsen roughness, mL/min	192	152	150	153	151
Brightness, %ISO	83.3	83.0	83.2	83.4	83.6
Opacity, %ISO	79.6	79.9	80.6	81.2	82.0
Scattering coefficient, m^2/kg	36.4	35.3	36.8	38.6	39.2
CIE whiteness	70.4	70.3	71.1	71.2	71.5
Yellowness	7.29	7.17	6.89	6.79	6.75
L*	95.2	95.0	95.1	94.9	94.9
a*	-0.08	-0.06	-0.09	-0.07	-0.03
b*	3.88	3.81	3.67	3.60	3.57

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 5 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHB with talc and CS, 5 kg/t at 15% ash level*

Table 12: Properties of MHB pulp with talc and amphoteric strength additive at 10 kg/t

Talc addition, %	Reference*	28	34	40	47
Retained ash, %	15.0	14.8	18.0	20.7	24.7
FPAR, %	68.6	67.7	70.9	72.5	77.3
CSF, ml	460	515	535	545	575
Streaming potential, mV	-256	-186	-222	-211	-229
Charge demand, µeq/L	5.0	4.0	4.7	5.5	5.9
Zeta potential, mV	-18.8	-9.5	-9.8	-12.0	-12.4
Conductivity, mS	0.428	0.485	0.475	0.463	0.447
Bulk, cc/g	1.31	1.31	1.33	1.33	1.34
Breaking length, m	3732	4210	4076	3974	3663
Burst index, kN/g	2.48	2.75	2.65	2.45	2.14
Tear index, $mN.m^2/g$	6.49	6.65	6.09	5.63	5.39
Double fold, no.	13	17	16	13	7
ZD tensile strength, kPa	676	676	656	634	624
Bending stiffness, mN.m	0.224	0.226	0.220	0.216	0.184
Air permeance, Gurley s	8.7	7.7	7.7	6.4	5.5
Bendtsen roughness, mL/min	192	137	139	138	143
Brightness, %ISO	83.3	82.9	83.0	83.2	83.2
Opacity, %ISO	79.6	80.6	81.0	81.4	81.9
Scattering coefficient, m^2/kg	36.4	35.0	36.2	37.1	38.0
CIE whiteness	70.4	69.9	70.2	71.2	71.5
Yellowness	7.29	7.25	7.23	6.88	6.54
L*	95.2	94.9	95.0	95.0	94.8
a*	-0.08	-0.10	-0.06	-0.01	0.04
b*	3.88	3.86	3.84	3.63	3.42

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 10 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHB with talc and CS, 5 kg/t at 15% ash level*

Table 13: Properties of MHB pulp with talc and amphoteric strength additive at 15 kg/t

Talc addition, %	Reference*	28	34	40	47
Retained ash, %	15.0	15.4	18.2	21.1	25.1
FPAR, %	68.6	70.4	71.7	73.9	78.5
CSF, ml	460	520	525	550	580
Streaming potential, mV	-256	-208	-189	-192	-180
Charge demand, µeq/L	5.0	3.2	3.6	4.4	4.7
Zeta potential, mV	-18.8	-8.2	-8.7	-9.2	-9.5
Conductivity, mS	0.428	0.477	0.49	0.485	0.477
Bulk, cc/g	1.31	1.30	1.29	1.28	1.29
Breaking length, m	3732	4323	4206	4145	3885
Burst index, kN/g	2.48	2.89	2.79	2.63	2.41
Tear index, $mN.m^2/g$	6.49	6.67	6.28	5.96	5.53
Double fold, no.	13	31	25	23	23
ZD tensile strength, kPa	676	688	674	657	652
Bending stiffness, mN.m	0.224	0.222	0.218	0.210	0.186
Air permeance, Gurley s	8.7	10.5	9.1	9.1	8.9
Bendtsen roughness, mL/min	192	140	133	140	139
Brightness, %ISO	83.3	82.6	82.8	83.1	83.4
Opacity, %ISO	79.6	80.4	80.7	81.2	82.1
Scattering coefficient, m^2/kg	36.4	35.3	35.9	36.8	37.7
CIE whiteness	70.4	70.4	70.6	71.0	71.0
Yellowness	7.29	7.02	6.91	6.82	6.96
L*	95.2	94.9	94.8	95.0	95.0
a*	-0.08	-0.08	-0.08	-0.10	-0.07
b*	3.88	3.73	3.67	3.58	3.65

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 15 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHB with talc and CS, 5 kg/t at 15% ash level*

Table 14: Properties of MHB pulp with talc and polymeric strength additive at 2 kg/t

Talc addition, %	Reference*	28	34	40	47
Retained ash, %	15.0	16.0	18.6	21.8	24.1
FPAR, %	68.6	73.1	73.3	76.3	75.4
CSF, ml	460	495	500	525	550
Streaming potential, mV	-256	-151	-225	-214	-207
Charge demand, µeq/L	5.0	4.7	4.8	5.6	5.9
Zeta potential, mV	-18.8	-16.7	-17.8	-21.7	-22.2
Conductivity, mS	0.428	0.458	0.457	0.442	0.455
Bulk, cc/g	1.31	1.29	1.32	1.28	1.25
Breaking length, m	3732	3286	3105	3004	2625
Burst index, kN/g	2.48	1.99	1.93	1.88	1.87
Tear index, $mN.m^2/g$	6.49	5.87	5.54	5.36	5.11
Double fold, no.	13	14	11	11	8
ZD tensile strength, kPa	676	648	627	613	600
Bending stiffness, mN.m	0.224	0.206	0.202	0.192	0.170
Air permeance, Gurley s	8.7	11.9	11.8	11.2	10.6
Bendtsen roughness, mL/min	192	132	135	126	123
Brightness, %ISO	83.3	82.7	82.8	83.3	83.8
Opacity, %ISO	79.6	79.7	80.1	80.8	80.9
Scattering coefficient, m^2/kg	36.4	36.0	36.9	37.0	37.6
CIE whiteness	70.4	70.6	71.0	71.5	72.5
Yellowness	7.29	6.89	6.78	6.65	6.38
L*	95.2	94.8	94.8	95.0	95.1
a*	-0.08	-0.01	-0.01	-0.08	-0.09
b*	3.88	3.63	3.56	3.54	3.40

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + PS, 2 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHB with talc and CS, 5 kg/t at 15% ash level*

Table 15: Properties of MHB pulp with talc and polymeric strength additive at 3 kg/t

Talc addition, %	Reference*	28	34	40	47
Retained ash, %	15.0	16.3	18.7	22.5	24.4
FPAR, %	68.6	74.5	73.7	78.8	76.4
CSF, ml	460	455	460	470	485
Streaming potential, mV	-256	-239	-234	-226	-207
Charge demand, µeq/L	5.0	5.0	6.4	6.7	7.0
Zeta potential, mV	-18.8	-18.0	-18.2	-19.3	-19.9
Conductivity, mS	0.428	0.459	0.452	0.456	0.476
Bulk, cc/g	1.31	1.30	1.27	1.26	1.28
Breaking length, m	3732	3310	3253	3148	3022
Burst index, kN/g	2.48	2.24	2.11	2.09	1.88
Tear index, $mN.m^2/g$	6.49	6.07	5.65	5.39	5.26
Double fold, no.	13	13	11	10	10
ZD tensile strength, kPa	676	660	640	631	628
Bending stiffness, mN.m	0.224	0.206	0.184	0.176	0.160
Air permeance, Gurley s	8.7	12.9	12.2	11.4	10.1
Bendtsen roughness, mL/min	192	124	109	114	124
Brightness, %ISO	83.3	82.9	83.2	83.7	84.0
Opacity, %ISO	79.6	80.3	80.8	81.0	81.3
Scattering coefficient, m^2/kg	36.4	35.2	36.7	37.3	38.9
CIE whiteness	70.4	70.7	71.2	71.7	72.6
Yellowness	7.29	6.85	6.74	6.56	6.33
L*	95.2	94.8	95.0	95.0	95.1
a*	-0.08	-0.08	-0.10	-0.06	-0.08
b*	3.88	3.64	3.59	3.47	3.37

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + PS, 3 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHB with talc and CS, 5 kg/t at 15% ash level*

Table 16: Properties of MHB pulp with talc and polymeric strength additive at 4 kg/t

Talc addition, %	Reference*	28	34	40	47
Retained ash, %	15.0	15.9	19.2	22.6	24.8
FPAR, %	68.6	72.7	75.7	79.1	77.6
CSF, ml	460	460	475	500	510
Streaming potential, mV	-256	-143	-189	-181	-164
Charge demand, µeq/L	5.0	5.2	5.4	5.9	6.4
Zeta potential, mV	-18.8	-18.2	-18.6	-18.6	-19.0
Conductivity, mS	0.428	0.463	0.462	0.469	0.472
Bulk, cc/g	1.31	1.30	1.26	1.25	1.28
Breaking length, m	3732	3577	3488	3266	3161
Burst index, kN/g	2.48	2.31	2.24	2.13	1.97
Tear index, $mN.m^2/g$	6.49	6.34	5.97	5.69	5.29
Double fold, no.	13	15	13	10	10
ZD tensile strength, kPa	676	669	661	647	638
Bending stiffness, mN.m	0.224	0.182	0.176	0.168	0.152
Air permeance, Gurley s	8.7	15.1	13.0	11.9	10.2
Bendtsen roughness, mL/min	192	104	105	110	106
Brightness, %ISO	83.3	82.6	83.0	83.3	84.0
Opacity, %ISO	79.6	80.1	80.4	80.6	80.9
Scattering coefficient, m^2/kg	36.4	34.8	35.4	35.6	37.4
CIE whiteness	70.4	70.8	71.3	72.0	72.6
Yellowness	7.29	6.90	6.61	6.45	6.31
L*	95.2	94.9	94.8	95.0	95.1
a*	-0.08	-0.04	-0.07	-0.06	-0.07
b*	3.88	3.85	3.51	3.42	3.35

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + PS, 4 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHB with talc and CS, 5 kg/t at 15% ash level*

Table 17: Properties of MHB pulp with talc and polymeric strength additive at 6 kg/t

Talc addition, %	Reference*	28	34	40	47
Retained ash, %	15.0	15.9	18.8	21.7	24.6
FPAR, %	68.6	72.9	74.1	76.6	76.9
CSF, ml	460	435	405	400	395
Streaming potential, mV	-256	-167	-235	-246	-255
Charge demand, µeq/L	5.0	6.2	5.9	6.7	7.1
Zeta potential, mV	-18.8	-13.2	-16.2	-16.2	-16.4
Conductivity, mS	0.428	0.457	0.460	0.461	0.475
Bulk, cc/g	1.31	1.29	1.27	1.27	1.26
Breaking length, m	3732	3834	3690	3494	3347
Burst index, kN/g	2.48	2.59	2.48	2.32	2.22
Tear index, $mN.m^2/g$	6.49	6.37	5.73	5.47	5.20
Double fold, no.	13	14	13	12	12
ZD tensile strength, kPa	676	738	706	665	625
Bending stiffness, mN.m	0.224	0.253	0.255	0.175	0.165
Air permeance, Gurley s	8.7	17.7	16.6	16.0	15.2
Bendtsen roughness, mL/min	192	105	105	102	101
Brightness, %ISO	83.3	82.6	83.0	83.5	83.7
Opacity, %ISO	79.6	80.1	80.0	80.9	81.3
Scattering coefficient, m^2/kg	36.4	33.5	34.3	36.3	37.5
CIE whiteness	70.4	70.7	70.8	72.0	72.3
Yellowness	7.29	7.09	6.97	6.52	6.19
L*	95.2	95.0	95.2	95.3	95.5
a*	-0.08	-0.05	-0.06	-0.06	-0.07
b*	3.88	3.84	3.81	3.46	3.28

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + PS, 6 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHB with talc and CS, 5 kg/t at 15% ash level*

Table 18: Properties of MHB pulp with talc and polymeric strength additive at 8 kg/t

Talc addition, %	Reference*	28	34	40	47
Retained ash, %	15.0	16.3	19.3	21.9	24.8
FPAR, %	68.6	74.6	76.0	76.6	77.6
CSF, ml	460	430	405	395	390
Streaming potential, mV	-256	-170	-240	-258	-265
Charge demand, µeq/L	5.0	6.5	6.7	7.0	7.5
Zeta potential, mV	-18.8	-15.3	-17.7	-17.5	-17.6
Conductivity, mS	0.428	0.474	0.463	0.468	0.478
Bulk, cc/g	1.31	1.28	1.26	1.26	1.25
Breaking length, m	3732	4040	3888	3740	3520
Burst index, kN/g	2.48	2.65	2.58	2.41	2.30
Tear index, $mN.m^2/g$	6.49	6.41	5.84	5.56	5.26
Double fold, no.	13	16	15	14	12
ZD tensile strength, kPa	676	715	703	673	647
Bending stiffness, mN.m	0.224	0.257	0.252	0.182	0.172
Air permeance, Gurley s	8.7	21.1	17.8	17.2	17.1
Bendtsen roughness, mL/min	192	106	107	101	100
Brightness, %ISO	83.3	82.6	83.0	83.1	83.3
Opacity, %ISO	79.6	80.2	80.4	81.1	81.5
Scattering coefficient, m^2/kg	36.4	33.6	35.0	36.5	37.8
CIE whiteness	70.4	70.6	70.8	70.5	72.0
Yellowness	7.29	7.06	7.09	6.86	6.29
L*	95.2	95.0	95.1	94.8	94.8
a*	-0.08	-0.04	-0.04	-0.07	-0.07
b*	3.88	3.85	3.76	3.76	3.33

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + PS, 8 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHB with talc and CS, 5 kg/t at 15% ash level*

Table 19: Properties of MHB pulp with talc and polymeric strength additive at 10 kg/t

Talc addition, %	Reference*	28	34	40	47
Retained ash, %	15.0	17.2	19.8	22.3	25.3
FPAR, %	68.6	78.6	78.1	78.0	79.1
CSF, ml	460	420	400	390	385
Streaming potential, mV	-256	-176	-255	-267	-268
Charge demand, µeq/L	5.0	7.5	7.8	8.1	8.6
Zeta potential, mV	-18.8	-18.2	-18.6	-17.8	-17.9
Conductivity, mS	0.428	0.444	0.474	0.478	0.481
Bulk, cc/g	1.31	1.27	1.26	1.26	1.26
Breaking length, m	3732	4272	4112	3883	3647
Burst index, kN/g	2.48	2.66	2.61	2.48	2.36
Tear index, $mN.m^2/g$	6.49	6.45	5.84	5.65	5.35
Double fold, no.	13	18	16	15	13
ZD tensile strength, kPa	676	726	695	682	652
Bending stiffness, mN.m	0.224	0.305	0.265	0.201	0.187
Air permeance, Gurley s	8.7	22.7	18.3	17.8	19.8
Bendtsen roughness, mL/min	192	109	107	100	99
Brightness, %ISO	83.3	82.6	82.8	83.0	83.1
Opacity, %ISO	79.6	80.4	80.6	81.3	81.6
Scattering coefficient, m^2/kg	36.4	33.8	35.9	36.8	38.2
CIE whiteness	70.4	70.4	70.4	70.0	71.6
Yellowness	7.29	6.86	7.01	6.96	6.46
L*	95.2	95.1	95.2	94.7	94.8
a*	-0.08	-0.04	-0.04	-0.07	-0.05
b*	3.88	3.75	3.73	3.74	3.41

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + PS, 10 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHB with talc and CS, 5 kg/t at 15% ash level*

Table 20: Properties of MHB pulp with GCC and cationic strength additive at 5 kg/t

GCC addition, %	Blank*	40	48	56	67
Retained ash, %	-	15.4	17.7	19.4	21.1
FPAR, %	-	53.9	54.6	54.0	52.6
CSF, ml	515	500	505	520	530
Streaming potential, mV	-248	-215	-209	-204	-190
Charge demand, µeq/L	9.8	8.0	6.5	5.9	4.7
Zeta potential, mV	-29.8	-14.0	-13.2	-12.9	-9.2
Conductivity, mS	0.491	0.465	0.459	0.450	0.444
Bulk, cc/g	1.34	1.34	1.33	1.28	1.28
Breaking length, m	4804	3623	3470	3283	2837
Burst index, kN/g	3.30	1.98	1.86	1.79	1.54
Tear index, $mN.m^2/g$	7.84	6.64	6.40	5.92	5.25
Double fold, no.	26	10	9	8	6
ZD tensile strength, kPa	661	720	708	682	642
Bending stiffness, mN.m	0.290	0.190	0.186	0.180	0.174
Air permeance, Gurley s	9.4	12.4	11.3	10.6	10.3
Bendtsen roughness, mL/min	121	101	106	103	91
Brightness, %ISO	83.0	85.3	85.9	86.4	87.0
Opacity, %ISO	78.4	83.7	84.4	85.8	86.3
Scattering coefficient, m^2/kg	34.6	45.9	48.5	51.3	54.1
CIE whiteness	69.4	75.6	75.8	76.8	78.0
Yellowness	7.84	5.38	5.59	5.34	5.02
L*	93.4	95.5	95.8	95.9	96.1
a*	-0.10	-0.21	-0.17	-0.14	-0.14
b*	4.20	2.92	3.02	2.88	2.72

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 5 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Blank: beaten pulp to 30^0 SR without addition of wet-end chemicals*

Table 21: Properties of MHB pulp with GCC and cationic strength additive at 10 kg/t

GCC addition, %	Reference*	40	48	56	67
Retained ash, %	15.4	15.6	18.1	20.4	21.9
FPAR, %	53.9	54.6	55.8	56.8	54.6
CSF, ml	500	500	510	520	525
Streaming potential, mV	-215	-212	-209	-204	-190
Charge demand, µeq/L	8.0	6.8	6.0	5.4	5.0
Zeta potential, mV	-14.0	-10.8	-7.9	-5.9	-4.8
Conductivity, mS	0.465	0.448	0.45	0.449	0.454
Bulk, cc/g	1.34	1.34	1.34	1.32	1.31
Breaking length, m	3623	3774	3669	3507	3288
Burst index, kN/g	1.98	2.61	2.37	2.21	1.93
Tear index, $mN.m^2/g$	6.64	6.79	6.61	6.38	6.21
Double fold, no.	10	13	11	10	10
ZD tensile strength, kPa	720	741	732	721	654
Bending stiffness, mN.m	0.190	0.212	0.210	0.206	0.206
Air permeance, Gurley s	12.4	14.7	12.5	12.4	13.3
Bendtsen roughness, mL/min	101	111	117	117	118
Brightness, %ISO	85.3	85.0	85.1	86.0	86.1
Opacity, %ISO	83.7	83.6	84.2	85	85.8
Scattering coefficient, m^2/kg	45.9	45.3	48.8	51.6	53.7
CIE whiteness	75.6	73.7	74.5	75.2	75.8
Yellowness	5.38	6.51	6.32	6.1	5.97
L*	95.5	95.7	95.9	95.9	96.1
a*	-0.21	-0.06	-0.07	-0.05	-0.08
b*	2.92	3.48	3.38	3.25	3.20

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 10 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHB with GCC and CS, 5 kg/t at 15% ash level*

Table 22: Properties of MHB pulp with GCC and cationic strength additive at 15 kg/t

GCC addition, %	Reference*	40	48	56	67
Retained ash, %	15.4	15.2	18.1	20.6	22.3
FPAR, %	53.9	53.2	55.8	57.4	55.6
CSF, ml	500	505	520	525	525
Streaming potential, mV	-215	-198	-187	-150	-146
Charge demand, µeq/L	8.0	6.2	6.3	5.5	4.5
Zeta potential, mV	-14.0	-7.5	-7.3	-6.3	-5.9
Conductivity, mS	0.465	0.451	0.45	0.46	0.462
Bulk, cc/g	1.34	1.36	1.34	1.34	1.32
Breaking length, m	3623	3945	3842	3540	3411
Burst index, kN/g	1.98	2.72	2.49	2.37	2.14
Tear index, $mN.m^2/g$	6.64	6.88	6.64	6.42	6.23
Double fold, no.	10	16	14	13	12
ZD tensile strength, kPa	720	757	746	730	691
Bending stiffness, mN.m	0.190	0.222	0.208	0.190	0.184
Air permeance, Gurley s	12.4	11.3	12.0	11.0	11.3
Bendtsen roughness, mL/min	101	90	89	93	89
Brightness, %ISO	85.3	85.2	85.9	85.5	86.2
Opacity, %ISO	83.7	83.3	84.2	85	86
Scattering coefficient, m^2/kg	45.9	44.7	48.4	51.0	54.2
CIE whiteness	75.6	74.3	75.8	75.2	76.4
Yellowness	5.38	6.37	5.88	5.99	5.69
L*	95.5	95.8	96.0	95.8	96.1
a*	-0.21	-0.09	-0.07	-0.08	-0.08
b*	2.92	3.42	3.14	3.21	3.05

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 15 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHB with GCC and CS, 5 kg/t at 15% ash level*

Table 23: Properties of MHB pulp with GCC and amphoteric strength additive at 5 kg/t

GCC addition, %	Reference*	40	48	56	67
Retained ash, %	15.4	15.5	18.6	21.1	23.0
FPAR, %	53.9	54.2	57.3	58.8	57.3
CSF, ml	500	525	530	530	545
Streaming potential, mV	-215	-264	-260	--223	-240
Charge demand, µeq/L	8.0	7.5	6.2	6.1	6.0
Zeta potential, mV	-14.0	-11.9	-8.7	-8.2	-7.0
Conductivity, mS	0.465	0.484	0.495	0.487	0.477
Bulk, cc/g	1.34	1.35	1.30	1.32	1.35
Breaking length, m	3623	3724	3511	3257	2858
Burst index, kN/g	1.98	2.14	1.86	1.55	1.40
Tear index, $mN.m^2/g$	6.64	6.64	6.11	5.64	5.17
Double fold, no.	10	14	10	9	8
ZD tensile strength, kPa	720	674	646	634	616
Bending stiffness, mN.m	0.190	0.218	0.216	0.206	0.156
Air permeance, Gurley s	12.4	11.3	11.3	10.3	10.4
Bendtsen roughness, mL/min	101	95	87	90	85
Brightness, %ISO	85.3	86.3	86.6	87.1	87.4
Opacity, %ISO	83.7	84.4	84.6	85.0	86.0
Scattering coefficient, m^2/kg	45.9	46.1	49.9	51.4	54.7
CIE whiteness	75.6	76.3	77.3	78.1	79.3
Yellowness	5.38	5.74	5.44	5.19	4.80
L*	95.5	96.0	96.2	96.2	96.3
a*	-0.21	-0.09	-0.08	-0.07	-0.09
b*	2.92	3.08	2.92	2.78	2.57

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 5 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHB with GCC and CS, 5 kg/t at 15% ash level*

Table 24: Properties of MHB pulp with GCC and amphoteric strength additive at 10 kg/t

GCC addition, %	Reference*	40	48	56	67
Retained ash, %	15.4	15.7	18.6	20.8	23.1
FPAR, %	53.9	54.9	57.4	57.9	57.6
CSF, ml	500	495	525	525	515
Streaming potential, mV	-215	-227	-212	-237	-220
Charge demand, µeq/L	8.0	5.8	5.2	4.8	4.3
Zeta potential, mV	-14.0	-7.5	-2.8	-2.7	-2.5
Conductivity, mS	0.465	0.452	0.461	0.455	0.455
Bulk, cc/g	1.34	1.35	1.30	1.32	1.33
Breaking length, m	3623	4012	3668	3424	3301
Burst index, kN/g	1.98	2.53	2.37	2.08	1.93
Tear index, $mN.m^2/g$	6.64	6.86	6.24	5.78	5.35
Double fold, no.	10	16	12	10	9
ZD tensile strength, kPa	720	728	688	659	636
Bending stiffness, mN.m	0.190	0.224	0.216	0.196	0.184
Air permeance, Gurley s	12.4	11.7	9.2	10.7	10.8
Bendtsen roughness, mL/min	101	91	92	94	84
Brightness, %ISO	85.3	85.6	86.2	86.7	86.7
Opacity, %ISO	83.7	84.2	84.5	85.4	86.2
Scattering coefficient, m^2/kg	45.9	46.4	49.7	51.7	55.0
CIE whiteness	75.6	75.6	76.2	77.5	78.2
Yellowness	5.38	5.87	5.81	5.32	5.20
L*	95.5	95.5	96.1	96.1	96.0
a*	-0.21	-0.09	-0.08	-0.09	-0.10
b*	2.92	3.15	3.12	2.86	2.80

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 10 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHB with GCC and CS, 5 kg/t at 15% ash level*

Table 25: Properties of MHB pulp with GCC and amphoteric strength additive at 15 kg/t

GCC addition, %	Reference*	40	48	56	67
Retained ash, %	15.4	16.1	18.4	20.9	23.4
FPAR, %	53.9	56.4	56.7	58.2	58.3
CSF, ml	500	520	525	535	555
Streaming potential, mV	-215	-224	-204	-201	-196
Charge demand, µeq/L	8.0	5.4	4.9	4.6	4.8
Zeta potential, mV	-14.0	-1.1	0.4	1.2	2.0
Conductivity, mS	0.465	0.456	0.446	0.457	0.462
Bulk, cc/g	1.34	1.34	1.31	1.33	1.34
Breaking length, m	3623	4150	3881	3676	3579
Burst index, kN/g	1.98	2.66	2.45	2.26	2.09
Tear index, $mN.m^2/g$	6.64	6.95	6.35	5.92	5.55
Double fold, no.	10	18	13	12	10
ZD tensile strength, kPa	720	750	703	686	668
Bending stiffness, mN.m	0.190	0.232	0.214	0.212	0.212
Air permeance, Gurley s	12.4	10.4	10.6	8.54	8.68
Bendtsen roughness, mL/min	101	89	88	92	81
Brightness, %ISO	85.3	85.9	86.2	86.3	86.6
Opacity, %ISO	83.7	83.8	84.4	85.1	86.8
Scattering coefficient, m^2/kg	45.9	45.6	49.0	51.1	54.6
CIE whiteness	75.6	75.8	76.6	76.8	78.4
Yellowness	5.38	5.80	5.28	5.50	5.00
L*	95.5	95.9	96.0	96.0	96.1
a*	-0.21	-0.08	-0.08	-0.11	-0.07
b*	2.92	3.10	2.99	2.96	2.68

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 15 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHB with GCC and CS, 5 kg/t at 15% ash level*

Table 26: Effect of PS dose on Ash, FPAR and strength properties of MHB pulp with GCC

Particular	PS, kg/t	CS, 5 kg/t	PS	CS, 5 kg/t	PS	CS, 5 kg/t	PS	CS, 5 kg/t	PS
GCC addition, %		400	400	480	480	560	560	670	670
Retained ash, %	4	15.4	13.3	17.7	16.5	19.4	18.2	21.1	20.9
	6		14.8		17.5		18.4		20.8
	8		14.5		15.3		16.4		17.8
	10		14.3		14.6		15.6		17.4
FPAR, %	4	53.9	46.6	54.6	50.9	54.0	50.9	52.6	52.1
	6		51.8		54.0		51.3		51.8
	8		50.8		47.2		45.7		44.4
	10		50.0		45.0		43.5		43.4
Breaking length, m	4	3623	4436	3470	4020	3283	3753	2837	3402
	6		4340		4060		3816		3523
Tear index, $mN.m^2/g$	4	6.64	6.02	6.40	5.85	5.92	5.61	5.25	5.52
	6		6.24		6.08		5.79		5.40

Table 27: Properties of MHB pulp with GCC and polymeric strength additive at 4 kg/t

GCC addition, %	Reference*	40	48	56	67
Retained ash, %	15.4	14.5	16.5	18.6	20.9
FPAR, %	53.9	50.8	54.2	52.4	52.2
CSF, ml	500	465	475	490	525
Streaming potential, mV	-215	-247	-213	-147	-171
Charge demand, µeq/L	8.0	6.2	5.7	5.3	4.8
Zeta potential, mV	-14.0	-12.2	-11.8	-10.7	-8.1
Conductivity, mS	0.465	0.433	0.432	0.43	0.428
Bulk, cc/g	1.34	1.34	1.32	1.29	1.28
Breaking length, m	3623	4436	4020	3753	3402
Burst index, kN/g	1.98	2.40	2.34	2.06	1.84
Tear index, $mN.m^2/g$	6.64	6.02	5.85	5.61	5.52
Double fold, no.	10	11	9	6	5
ZD tensile strength, kPa	720	655	641	626	610
Bending stiffness, mN.m	0.190	0.220	0.210	0.196	0.184
Air permeance, Gurley s	12.4	13.0	10.7	10.5	9.6
Bendtsen roughness, mL/min	101	92	98	94	92
Brightness, %ISO	85.3	85.5	86.0	86.5	86.8
Opacity, %ISO	83.7	82.7	84.8	85.3	86.1
Scattering coefficient, m^2/kg	45.9	42.5	45.8	47.4	51.5
CIE whiteness	75.6	74.8	75.6	77.8	77.6
Yellowness	5.38	6.00	5.78	5.27	5.30
L*	95.5	95.7	96.0	96.1	96.2
a*	-0.21	-0.11	-0.13	-0.12	-0.11
b*	2.92	3.22	3.11	2.87	2.86

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + PS, 4 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHB with GCC and CS, 5 kg/t at 15% ash level*

Table 28: Properties of MHB pulp with GCC and polymeric strength additive at 6 kg/t

GCC addition, %	Reference*	40	48	56	67
Retained ash, %	15.4	14.8	16.8	18.8	21.2
FPAR, %	53.9	51.8	54.9	52.4	52.8
CSF, ml	500	475	485	520	525
Streaming potential, mV	-215	-257	-254	-238	-218
Charge demand, µeq/L	8.0	7.5	7.2	6.4	6.2
Zeta potential, mV	-14.0	-15.1	-12.8	-11.5	-9.5
Conductivity, mS	0.465	0.432	0.427	0.428	0.428
Bulk, cc/g	1.34	1.34	1.33	1.28	1.27
Breaking length, m	3623	4340	4060	3816	3523
Burst index, kN/g	1.98	2.46	2.36	2.17	2.08
Tear index, $mN.m^2/g$	6.64	6.24	6.08	5.79	5.40
Double fold, no.	10	11	10	9	6
ZD tensile strength, kPa	720	690	661	635	617
Bending stiffness, mN.m	0.190	0.216	0.200	0.192	0.176
Air permeance, Gurley s	12.4	14.8	12.4	11.0	10.4
Bendtsen roughness, mL/min	101	90	85	87	85
Brightness, %ISO	85.3	85.0	85.6	86.4	86.6
Opacity, %ISO	83.7	83.5	84.3	85.6	86.8
Scattering coefficient, m^2/kg	45.9	42.5	45.8	47.4	51.5
CIE whiteness	75.6	74.4	74.7	76.5	77.4
Yellowness	5.38	6.29	6.03	5.43	5.25
L*	95.5	95.8	95.7	95.9	96.0
a*	-0.21	-0.03	-0.06	-0.06	-0.05
b*	2.92	3.36	3.22	2.78	2.75

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + PS, 6 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHB with GCC and CS, 5 kg/t at 15% ash level*

Table 29: Properties of MHB pulp with PCC and cationic strength additive at 5 kg/t

PCC addition, %	Blank*	30	36	44	52
Retained ash, %	-	15.5	18.2	20.6	23.7
FPAR, %	-	67.1	68.8	67.4	69.3
CSF, ml	515	465	480	495	505
Streaming potential, mV	-248	-198	-190	-215	-260
Charge demand, µeq/L	9.8	9.8	8.5	8.0	7.1
Zeta potential, mV	-29.8	-19.3	-18.8	-17.9	-17.0
Conductivity, mS	0.491	0.492	0.487	0.499	0.498
Bulk, cc/g	1.34	1.51	1.52	1.54	1.52
Breaking length, m	4804	3158	3070	2752	2532
Burst index, kN/g	3.30	1.91	1.64	1.50	1.46
Tear index, $mN.m^2/g$	7.84	6.57	6.02	5.57	5.29
Double fold, no.	26	12	6	5	5
ZD tensile strength, kPa	661	585	575	538	518
Bending stiffness, mN.m	0.290	0.264	0.240	0.214	0.188
Air permeance, Gurley s	9.4	5.9	5.6	5.3	4.2
Bendtsen roughness, mL/min	121	155	147	166	156
Brightness, %ISO	83.0	85.8	86.2	86.4	87.2
Opacity, %ISO	78.4	85.8	86.6	88.3	90.2
Scattering coefficient, m^2/kg	34.6	54.9	59.5	61.5	62.5
CIE whiteness	69.4	75.0	76.1	76.2	77.8
Yellowness	7.84	6.25	5.83	5.92	5.53
L*	93.4	96.0	96.0	96.2	96.4
a*	-0.10	-0.06	-0.07	-0.08	-0.01
b*	4.20	3.35	3.12	3.18	2.95

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 5 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Blank: beaten pulp to 30^0 SR without addition of wet-end chemicals*

Table 30: Properties of MHB pulp with PCC and cationic strength additive at 10 kg/t

PCC addition, %	Reference*	30	36	44	52
Retained ash, %	15.5	15.6	17.9	20.8	22.9
FPAR, %	65.0	67.6	67.6	68.1	66.9
CSF, ml	465	470	490	500	510
Streaming potential, mV	-198	-231	-206	-165	-190
Charge demand, µeq/L	7.1	8.4	6.9	5.9	5.6
Zeta potential, mV	-17.9	-14.1	-13.8	-13.3	-13.3
Conductivity, mS	0.492	0.491	0.507	0.497	0.499
Bulk, cc/g	1.51	1.49	1.51	1.51	1.53
Breaking length, m	3158	3377	3208	3019	2862
Burst index, kN/g	1.91	1.94	1.88	1.81	1.76
Tear index, $mN.m^2/g$	6.57	6.74	6.23	6.09	5.90
Double fold, no.	12	14	8	7	8
ZD tensile strength, kPa	585	614	598	585	579
Bending stiffness, mN.m	0.264	0.250	0.210	0.204	0.200
Air permeance, Gurley s	5.9	4.9	4.5	4.4	4.2
Bendtsen roughness, mL/min	155	157	154	154	151
Brightness, %ISO	85.8	85.7	86.1	86.7	86.8
Opacity, %ISO	85.8	86.3	87.2	88.5	89.4
Scattering coefficient, m^2/kg	54.9	54.9	59.5	61.7	62.5
CIE whiteness	75.0	75.6	76.0	76.9	77.5
Yellowness	6.25	5.90	6.82	5.76	5.36
L*	96.0	95.9	96.0	96.3	96.2
a*	-0.06	-0.01	-0.07	-0.06	-0.09
b*	3.35	3.13	3.13	3.09	2.88

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 10 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: MHB with PCC and CS, 5 kg/t at 15% ash level*

Table 31: Properties of MHB pulp with PCC and cationic strength additive at 15 kg/t

PCC addition, %	Reference*	30	36	44	52
PCC addition, %	30	30	36	44	52
Retained ash, %	15.5	15.1	18.0	20.4	23.0
FPAR, %	65.0	65.4	68.0	66.8	67.2
CSF, ml	465	480	495	500	520
Streaming potential, mV	-198	-167	-187	-198	-200
Charge demand, µeq/L	7.1	7.8	7.4	7.2	5.3
Zeta potential, mV	-17.9	-10.2	-9.8	-9.2	-8.8
Conductivity, mS	0.492	0.486	0.495	0.503	0.505
Bulk, cc/g	1.51	1.50	1.52	1.50	1.52
Breaking length, m	3158	3882	3606	3386	3111
Burst index, kN/g	1.91	2.25	2.00	1.82	1.78
Tear index, $Mn.m^2/g$	6.57	6.91	6.65	6.26	6.04
Double fold, no.	12	16	11	10	11
ZD tensile strength, kPa	585	663	611	591	592
Bending stiffness, mN.m	0.264	0.224	0.196	0.196	0.194
Air permeance, Gurley s	5.9	5.2	4.7	4.6	4.3
Bendtsen roughness, mL/min	155	153	160	160	148
Brightness, %ISO	85.8	85.3	85.8	86.2	86.8
Opacity, %ISO	85.8	86.5	88.4	89.4	91.4
Scattering coefficient, m^2/kg	54.9	55.4	60.0	63.1	64.7
CIE whiteness	75.0	74.3	76.0	76.2	76.5
Yellowness	6.25	6.18	5.93	5.77	5.98
L*	96.0	95.7	96.2	96.2	96.3
a*	-0.06	-0.13	-0.08	-0.13	-0.03
b*	3.35	3.33	3.18	3.11	3.19

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 15 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: MHB with PCC and CS, 5 kg/t at 15% ash level*

Table 32: Properties of MHB pulp with PCC and amphoteric strength additive at 5 kg/t

PCC addition, %	Reference*	30	36	44	52
PCC addition, %	30	30	36	44	52
Retained ash, %	15.5	15.5	17.8	20.6	23.2
FPAR, %	65.0	67.2	67.2	67.4	67.8
CSF, ml	465	465	470	480	495
Streaming potential, mV	-198	-165	-160	-154	-150
Charge demand, µeq/L	7.1	12.5	11.9	8.5	8.0
Zeta potential, mV	-17.9	-17.6	-16.5	-15.3	-14.5
Conductivity, mS	0.492	0.496	0.497	0.504	0.506
Bulk, cc/g	1.51	1.48	1.46	1.49	1.52
Breaking length, m	3158	3600	3484	3364	3141
Burst index, kN/g	1.91	2.02	1.94	1.77	1.57
Tear index, $mN.m^2/g$	6.57	6.18	5.89	5.47	5.14
Double fold, no.	12	9	7	6	5
ZD tensile strength, kPa	585	631	610	585	558
Bending stiffness, mN.m	0.264	0.222	0.216	0.208	0.202
Air permeance, Gurley s	5.9	7.0	6.4	5.8	5.6
Bendtsen roughness, mL/min	155	123	120	111	136
Brightness, %ISO	85.8	86.0	86.5	86.8	87.2
Opacity, %ISO	85.8	85.7	86.7	87.4	88.3
Scattering coefficient, m^2/kg	54.9	50.4	54.9	55.2	56.0
CIE whiteness	75.0	76.0	76.8	77.9	78.6
Yellowness	6.25	6.30	5.99	5.55	4.88
L*	96.0	96.1	96.2	96.1	96.1
a*	-0.06	-0.06	-0.07	-0.05	-0.06
b*	3.35	3.37	3.21	2.95	2.61

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 5 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: MHB with PCC and CS, 5 kg/t at 15% ash level*

Table 33: Properties of MHB pulp with PCC and amphoteric strength additive at 10 kg/t

PCC addition, %	Reference*	30	36	44	52
Retained ash, %	15.5	16.3	18.0	20.9	23.7
FPAR, %	65.0	69.3	68.0	68.4	69.3
CSF, ml	465	510	520	530	550
Streaming potential, mV	-198	-160	-174	-179	-181
Charge demand, µeq/L	7.1	8.8	7.4	6.3	5.0
Zeta potential, mV	-17.9	-11.4	-11.3	-10.5	-10.0
Conductivity, mS	0.492	0.498	0.501	0.504	0.502
Bulk, cc/g	1.51	1.48	1.50	1.50	1.51
Breaking length, m	3158	3941	3838	3623	3553
Burst index, kN/g	1.91	2.20	2.07	1.82	1.62
Tear index, $mN.m^2/g$	6.57	6.61	6.10	5.84	5.36
Double fold, no.	12	9	10	6	5
ZD tensile strength, kPa	585	652	646	632	602
Bending stiffness, mN.m	0.264	0.244	0.224	0.220	0.212
Air permeance, Gurley s	5.9	6.9	6.6	6.3	6.1
Bendtsen roughness, mL/min	155	114	113	137	136
Brightness, %ISO	85.8	85.8	86.4	86.7	87.2
Opacity, %ISO	85.8	86.0	87.1	87.6	88.7
Scattering coefficient, m^2/kg	54.9	50.6	55.3	56.3	57.4
CIE whiteness	75.0	76.0	76.8	77.5	78.0
Yellowness	6.25	6.13	5.92	5.26	5.11
L*	96.0	95.9	96.0	96.0	96.1
a*	-0.06	-0.05	-0.05	-0.07	-0.07
b*	3.35	3.27	3.16	2.81	2.74

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 10 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: MHB with PCC and CS, 5 kg/t at 15% ash level*

Table 34: Properties of MHB pulp with PCC and amphoteric strength additive at 15 kg/t

PCC addition, %	Reference*	30	36	44	52
Retained ash, %	15.5	16.5	18.3	21.3	24.0
FPAR, %	65.0	71.5	69.1	69.7	70.2
CSF, ml	465	515	530	540	555
Streaming potential, mV	-198	-180	-180	-172	-165
Charge demand, µeq/L	7.1	4.9	4.5	4.2	3.8
Zeta potential, mV	-17.9	-6.2	-5.4	-4.9	-4.2
Conductivity, mS	0.492	0.496	0.496	0.494	0.491
Bulk, cc/g	1.51	1.44	1.46	1.47	1.47
Breaking length, m	3158	4136	3944	3798	3653
Burst index, kN/g	1.91	2.42	2.31	2.15	2.02
Tear index, $mN.m^2/g$	6.57	6.73	6.44	6.12	5.97
Double fold, no.	12	15	14	12	10
ZD tensile strength, kPa	585	690	686	653	617
Bending stiffness, mN.m	0.264	0.258	0.232	0.216	0.196
Air permeance, Gurley s	5.9	7.2	6.6	6.3	5.5
Bendtsen roughness, mL/min	155	143	138	130	130
Brightness, %ISO	85.8	85.2	86.1	86.7	86.8
Opacity, %ISO	85.8	86.1	87.1	88.0	88.6
Scattering coefficient, m^2/kg	54.9	51.3	56.8	57.7	58.4
CIE whiteness	75.0	75.1	75.9	76.9	77.4
Yellowness	6.25	5.74	5.63	5.31	5.28
L*	96.0	95.5	95.8	96.0	96.0
a*	-0.06	-0.04	-0.09	-0.09	-0.11
b*	3.35	3.04	3.02	2.85	2.84

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 15 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: MHB with PCC and CS, 5 kg/t at 15% ash level*

Table 35: Properties of MHB pulp with PCC and polymeric strength additive at 6 kg/t

PCC addition, %	Reference*	30	36	44	52
Retained ash, %	15.5	15.1	17.1	19.3	21.8
FPAR, %	65.0	65.6	64.5	63.1	63.7
CSF, ml	465	385	395	415	425
Streaming potential, mV	-198	-112	-100	-105	-95
Charge demand, µeq/L	7.1	8.4	8.0	7.2	6.8
Zeta potential, mV	-17.9	-9.4	-8.6	-8.2	-7.6
Conductivity, mS	0.492	0.400	0.402	0.405	0.412
Bulk, cc/g	1.51	1.40	1.41	1.42	1.44
Breaking length, m	3158	3609	3488	3235	3107
Burst index, kN/g	1.91	2.39	2.12	1.99	1.83
Tear index, $mN.m^2/g$	6.57	6.34	6.29	6.14	6.03
Double fold, no.	12	16	12	9	7
ZD tensile strength, kPa	585	681	655	621	606
Bending stiffness, mN.m	0.264	0.210	0.197	0.175	0.157
Air permeance, Gurley s	5.9	17.6	14.4	12.1	11.3
Bendtsen roughness, mL/min	155	115	104	94	88
Brightness, %ISO	85.8	85.6	86.4	87.1	87.9
Opacity, %ISO	85.8	85.2	86.2	86.4	86.9
Scattering coefficient, m^2/kg	54.9	55.8	57.7	58.6	62.4
CIE whiteness	75.0	76.0	76.4	76.8	77.7
Yellowness	6.25	5.72	5.69	5.52	5.36
L*	96.0	95.9	95.9	96.1	96.2
a*	-0.06	-0.17	-0.18	-0.21	-0.22
b*	3.35	3.24	3.18	3.11	3.08

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + PS, 6 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: MHB with PCC and CS, 5 kg/t at 15% ash level*

Table 36: Properties of MHB pulp with PCC and polymeric strength additive at 8 kg/t

PCC addition, %	Reference*	30	36	44	52
Retained ash, %	15.5	14.5	16.8	18.6	21.1
FPAR, %	65.0	62.9	63.3	60.7	61.7
CSF, ml	465	390	395	420	430
Streaming potential, mV	-198	-123	-121	-133	-109
Charge demand, µeq/L	7.1	10.3	8.4	7.7	6.3
Zeta potential, mV	-17.9	-10.5	-9.7	-9.2	-8.7
Conductivity, mS	0.492	0.395	0.407	0.420	0.422
Bulk, cc/g	1.51	1.39	1.39	1.41	1.43
Breaking length, m	3158	3784	3677	3518	3376
Burst index, kN/g	1.91	2.59	2.41	2.20	2.06
Tear index, $mN.m^2/g$	6.57	6.61	6.42	6.28	6.20
Double fold, no.	12	19	16	12	9
ZD tensile strength, kPa	585	690	671	638	618
Bending stiffness, mN.m	0.264	0.225	0.205	0.206	0.161
Air permeance, Gurley s	5.9	17.2	14.5	13.0	10.9
Bendtsen roughness, mL/min	155	115	107	95	90
Brightness, %ISO	85.8	85.4	85.8	86.5	86.7
Opacity, %ISO	85.8	85.4	85.8	86.3	87.1
Scattering coefficient, m^2/kg	54.9	53.6	56.5	57.3	63.1
CIE whiteness	75.0	75.1	76.1	76.3	76.8
Yellowness	6.25	5.93	5.78	5.69	5.79
L*	96.0	95.8	95.9	96.0	96.1
a*	-0.06	-0.10	-0.10	-0.11	-0.12
b*	3.35	3.19	3.14	2.98	2.87

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + PS, 8 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: MHB with PCC and CS, 5 kg/t at 15% ash level*

Table 37: Properties of MHB pulp with PCC and polymeric strength additive at 10 kg/t

PCC addition, %	Reference*	30	36	44	52
Retained ash, %	15.5	14.2	16.1	17.8	20.8
FPAR, %	65.0	61.4	60.9	58.4	60.7
CSF, ml	465	390	400	420	435
Streaming potential, mV	-198	-109	-118	-105	-80
Charge demand, µeq/L	7.1	10.6	9.1	8.4	7.3
Zeta potential, mV	-17.9	-13.6	-12.2	-11.1	-10.1
Conductivity, mS	0.492	0.406	0.427	0.431	0.437
Bulk, cc/g	1.51	1.38	1.38	1.40	1.42
Breaking length, m	3158	4057	3867	3693	3486
Burst index, kN/g	1.91	2.69	2.55	2.36	2.25
Tear index, $mN.m^2/g$	6.57	6.86	6.50	6.34	6.31
Double fold, no.	12	22	18	15	11
ZD tensile strength, kPa	585	729	704	692	679
Bending stiffness, mN.m	0.264	0.240	0.219	0.210	0.197
Air permeance, Gurley s	5.9	17.0	13.8	13.2	11.0
Bendtsen roughness, mL/min	155	116	105	94	95
Brightness, %ISO	85.8	84.9	85.4	86.0	86.3
Opacity, %ISO	85.8	85.1	84.6	85.5	86.7
Scattering coefficient, m^2/kg	54.9	52.1	54.2	56.8	59.8
CIE whiteness	75.0	74.9	75.4	75.6	76.3
Yellowness	6.25	5.95	5.80	5.50	5.35
L*	96.0	95.7	95.7	96.1	96.2
a*	-0.06	-0.07	-0.05	-0.06	-0.06
b*	3.35	3.19	3.04	2.95	2.87

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + PS, 10 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: MHB with PCC and CS, 5 kg/t at 15% ash level*

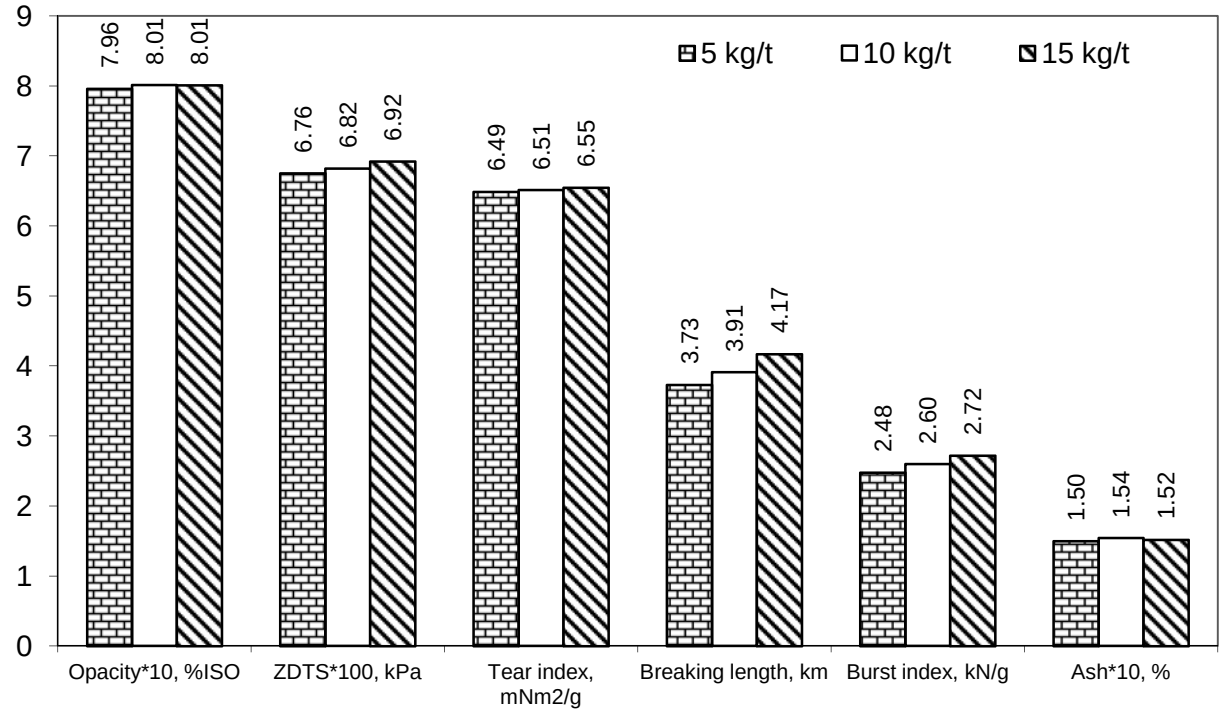

Figure 1: Effect of CS on properties of MHB pulp at 280 kg/t addition of talc

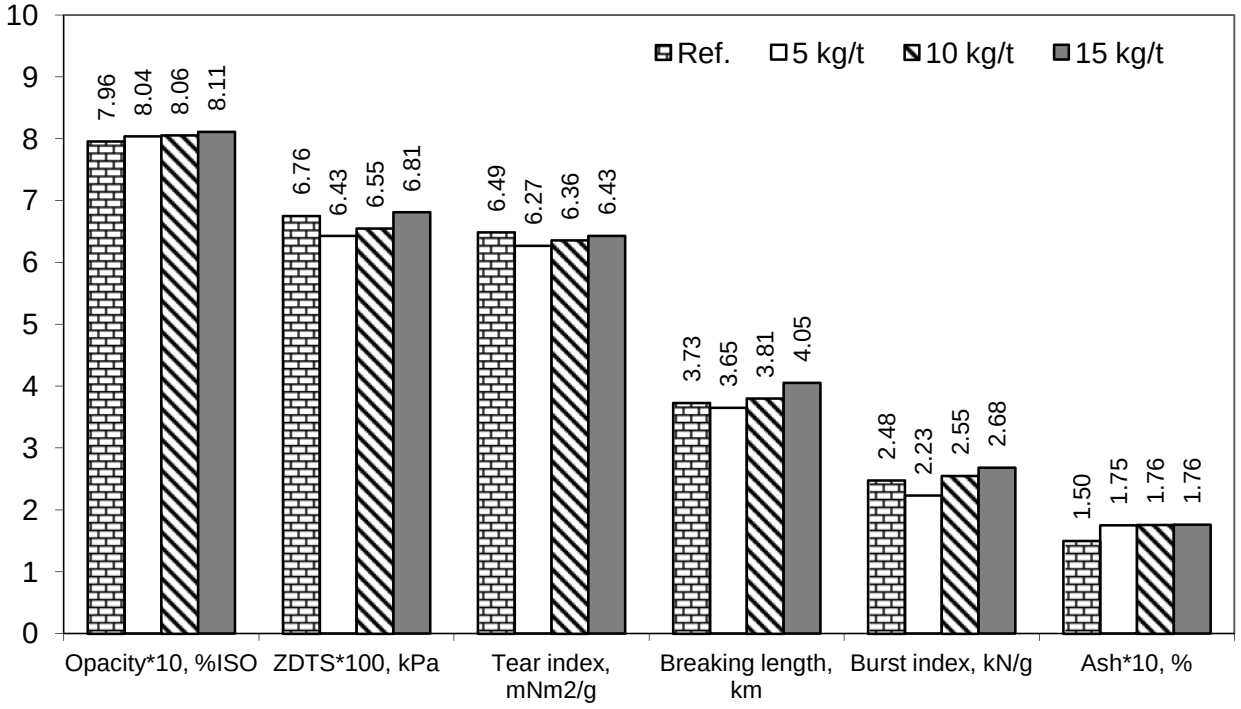

Figure 2: Effect of CS on properties of MHB pulp at 340 kg/t addition of talc

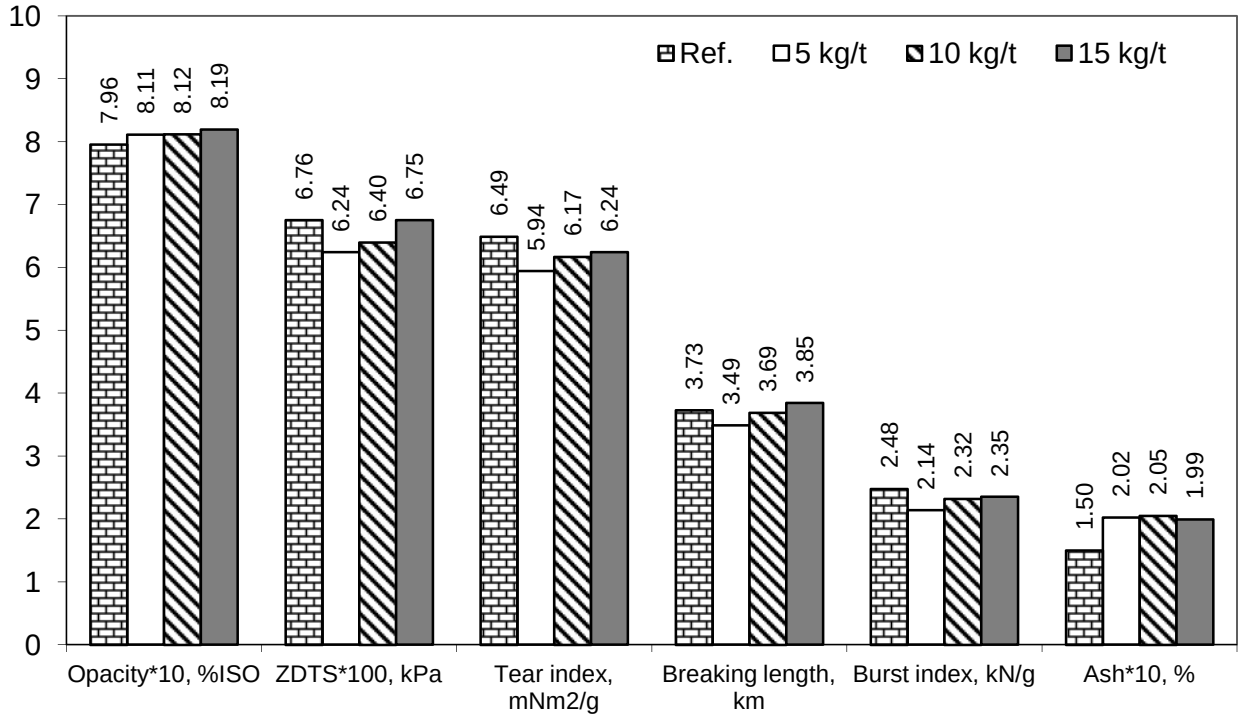

Figure 3: Effect of CS on properties of MHB pulp at 400 kg/t addition of talc

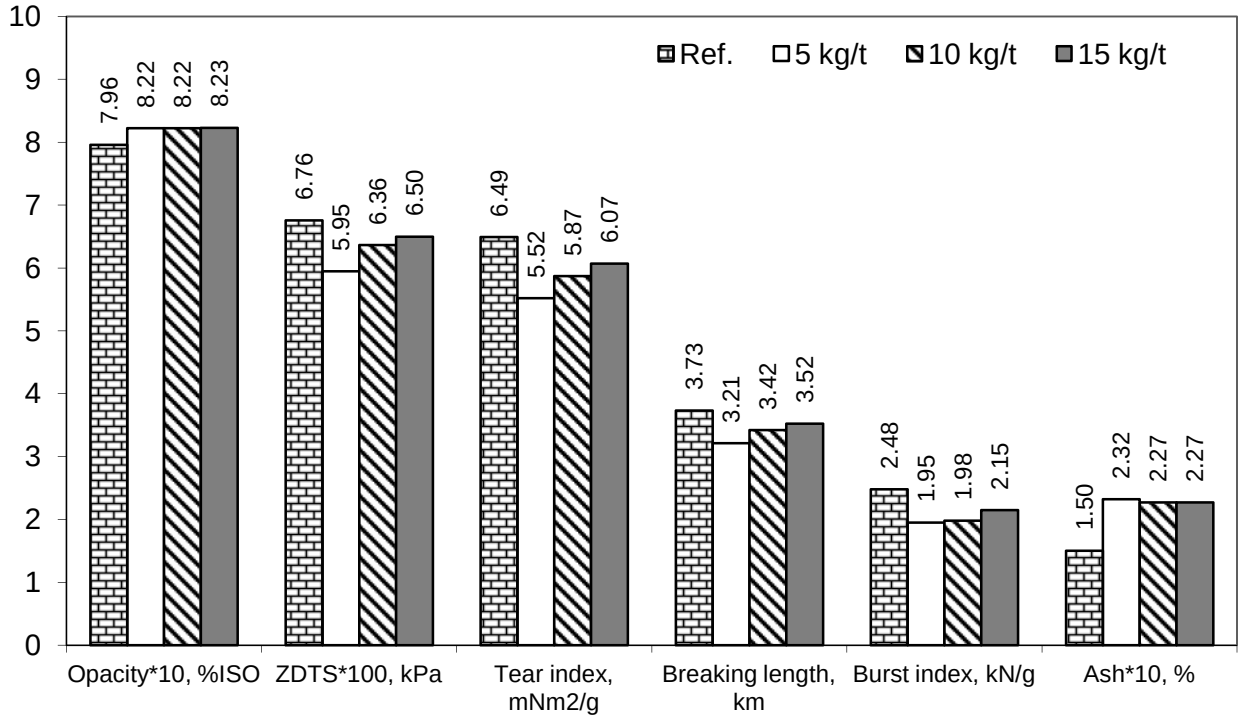

Figure 4: Effect of CS on properties of MHB pulp at 470 kg/t addition of talc

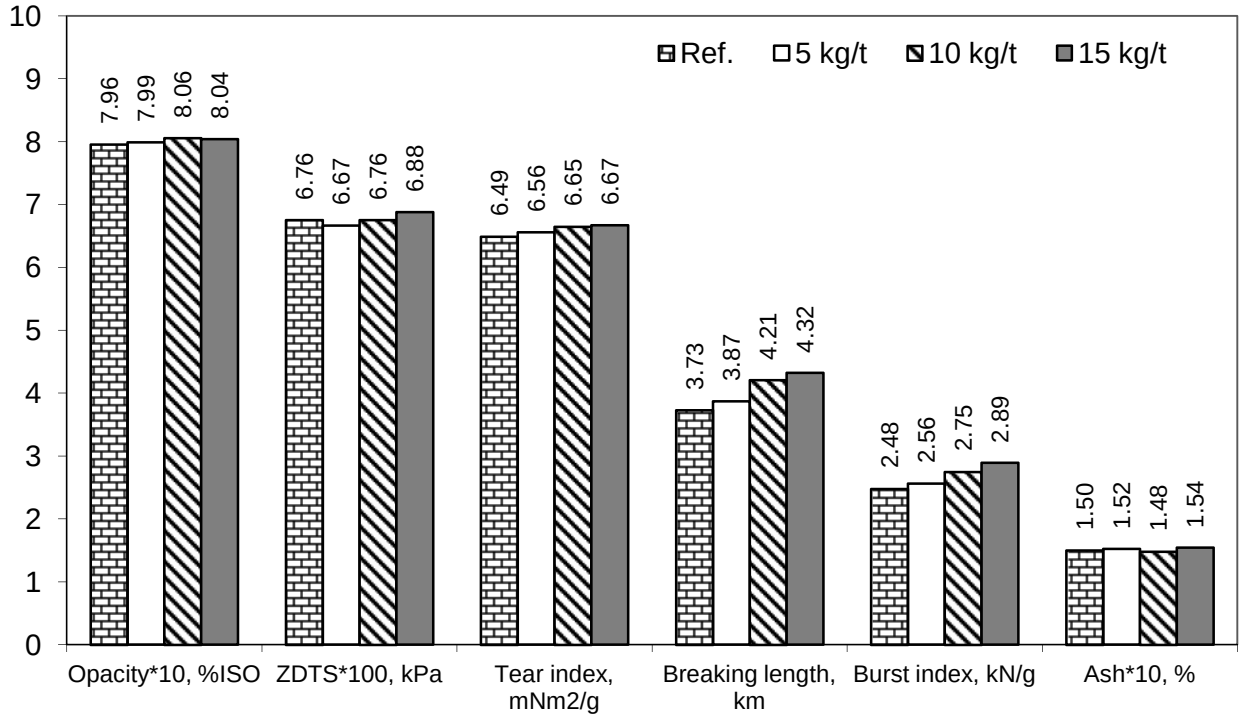

Figure 5: Effect of AS on properties of MHB pulp at 280 kg/t addition of talc

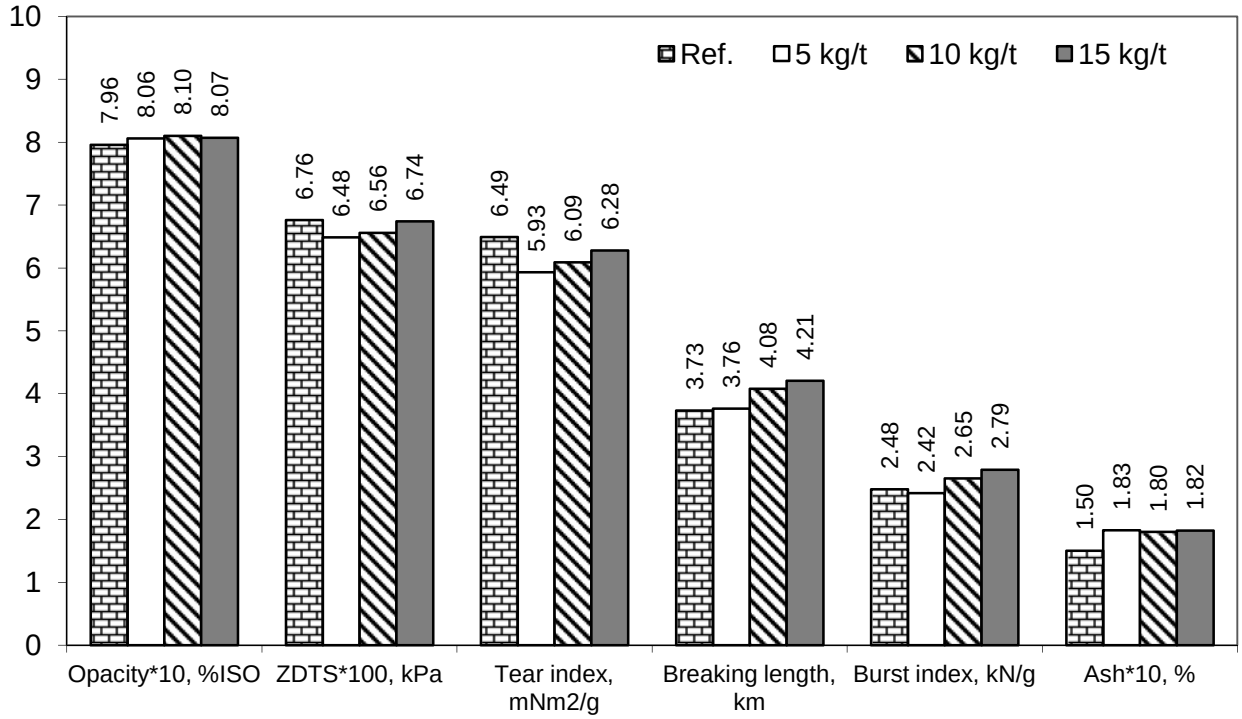

Figure 6: Effect of AS on properties of MHB pulp at 340 kg/t addition of talc

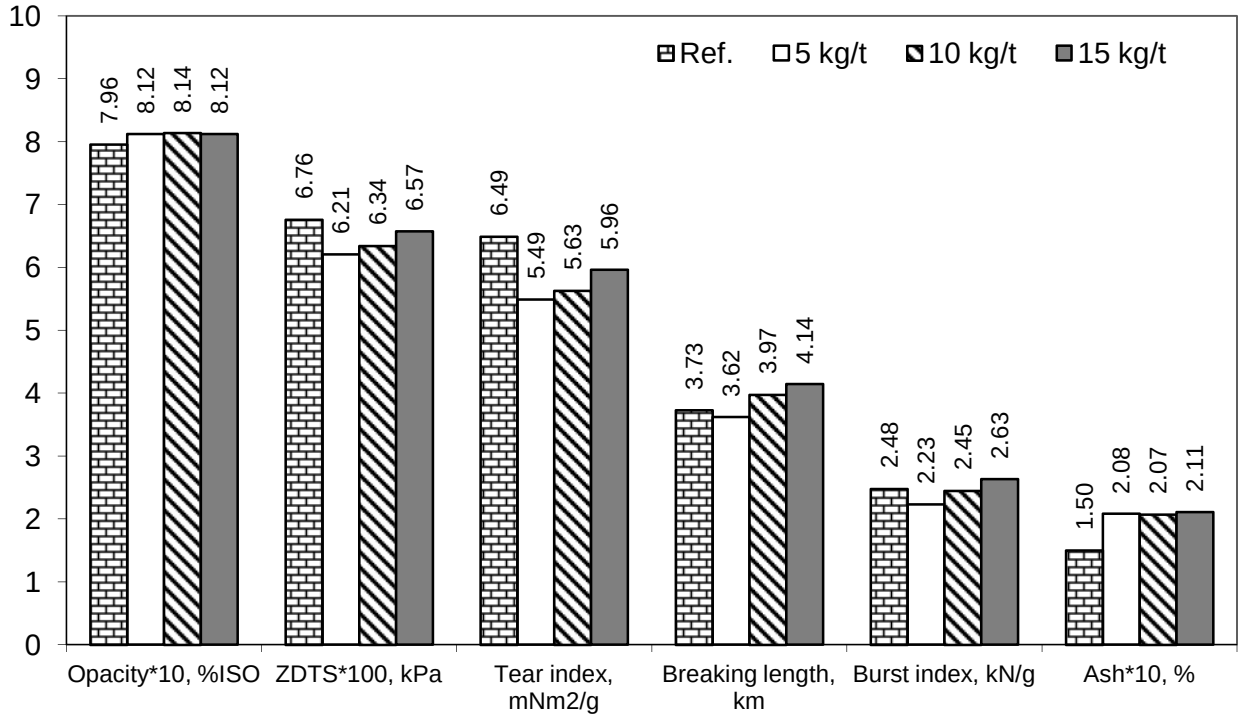

Figure 7: Effect of AS on properties of MHB pulp at 400 kg/t addition of talc

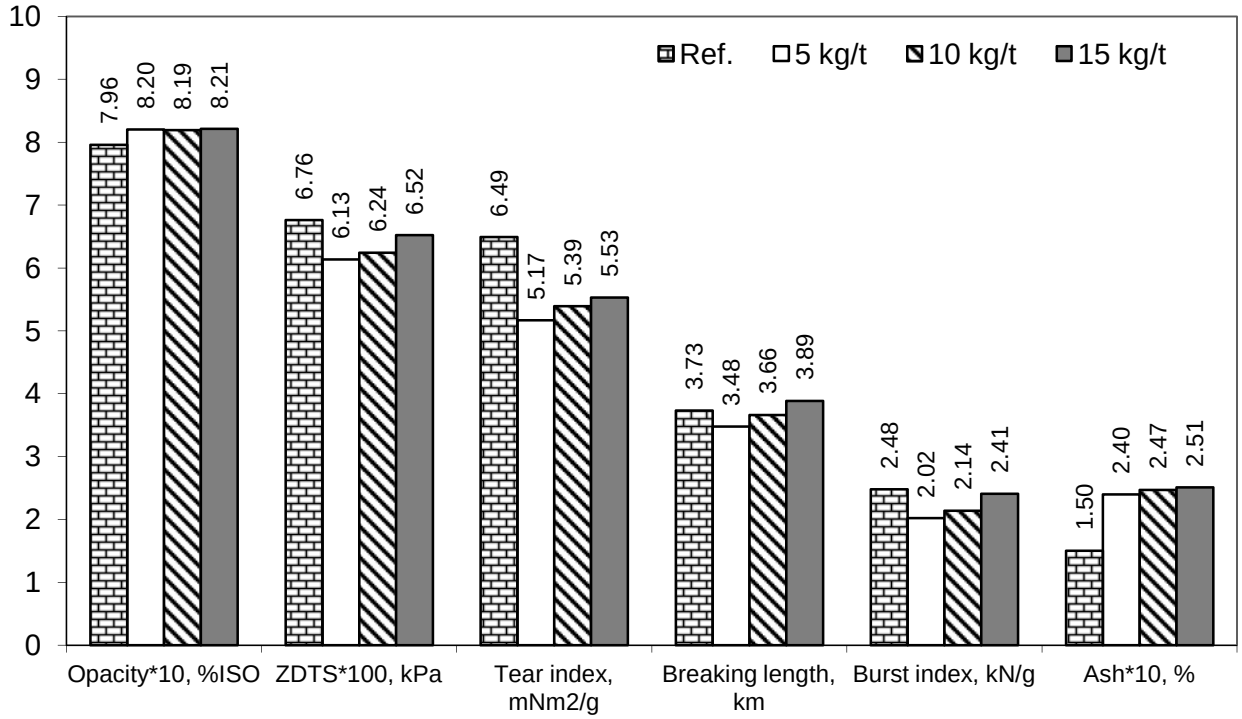

Figure 8: Effect of AS on properties of MHB pulp at 470 kg/t addition of talc

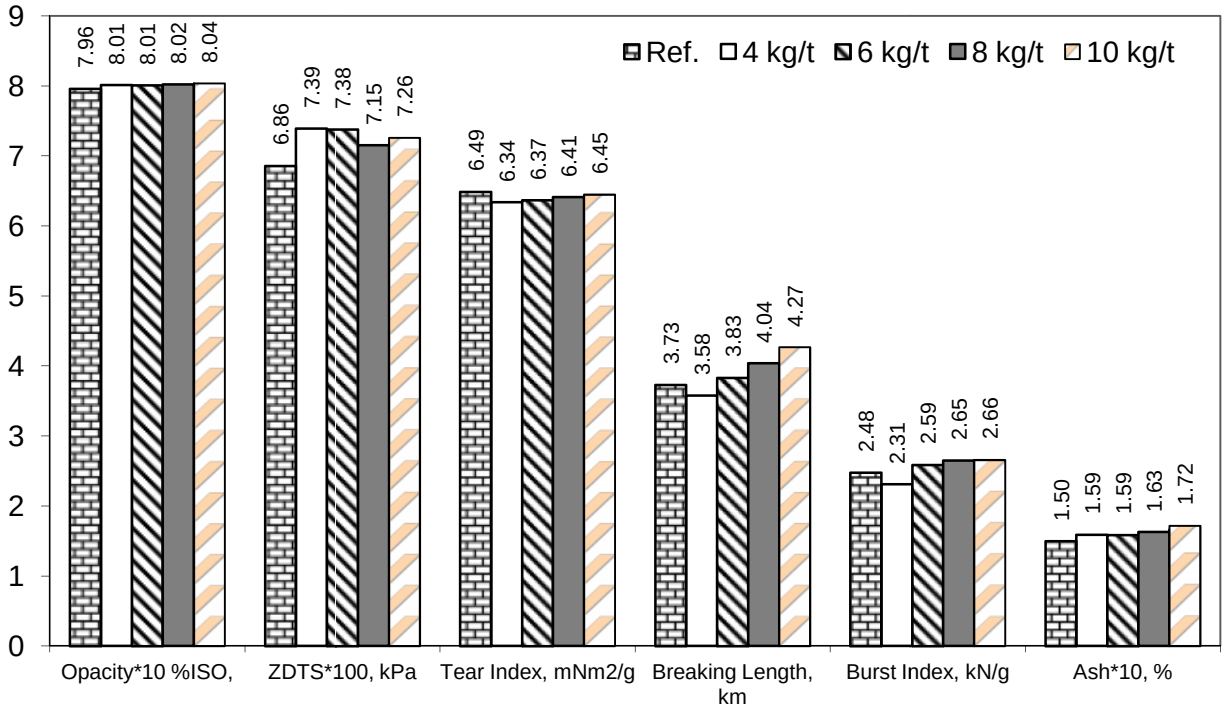

Figure 9: Effect of PS on properties of MHB pulp at 280 kg/t addition of talc

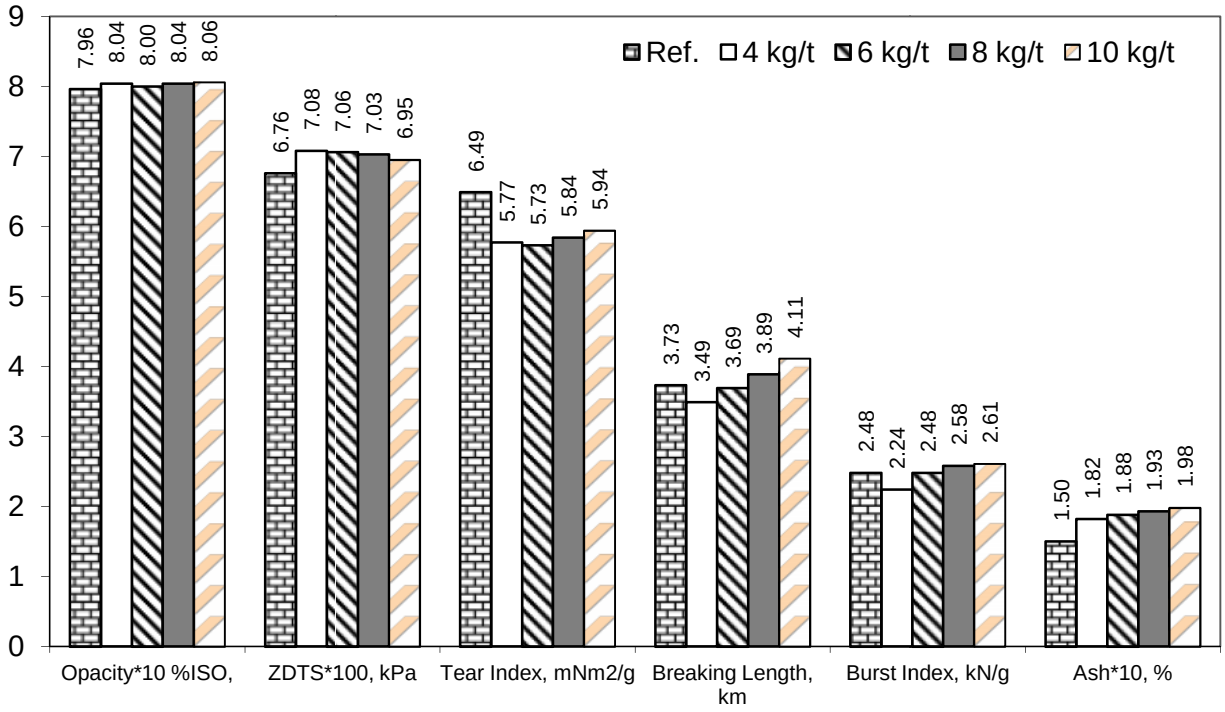

Figure 10: Effect of PS on properties of MHB pulp at 340 kg/t addition of talc

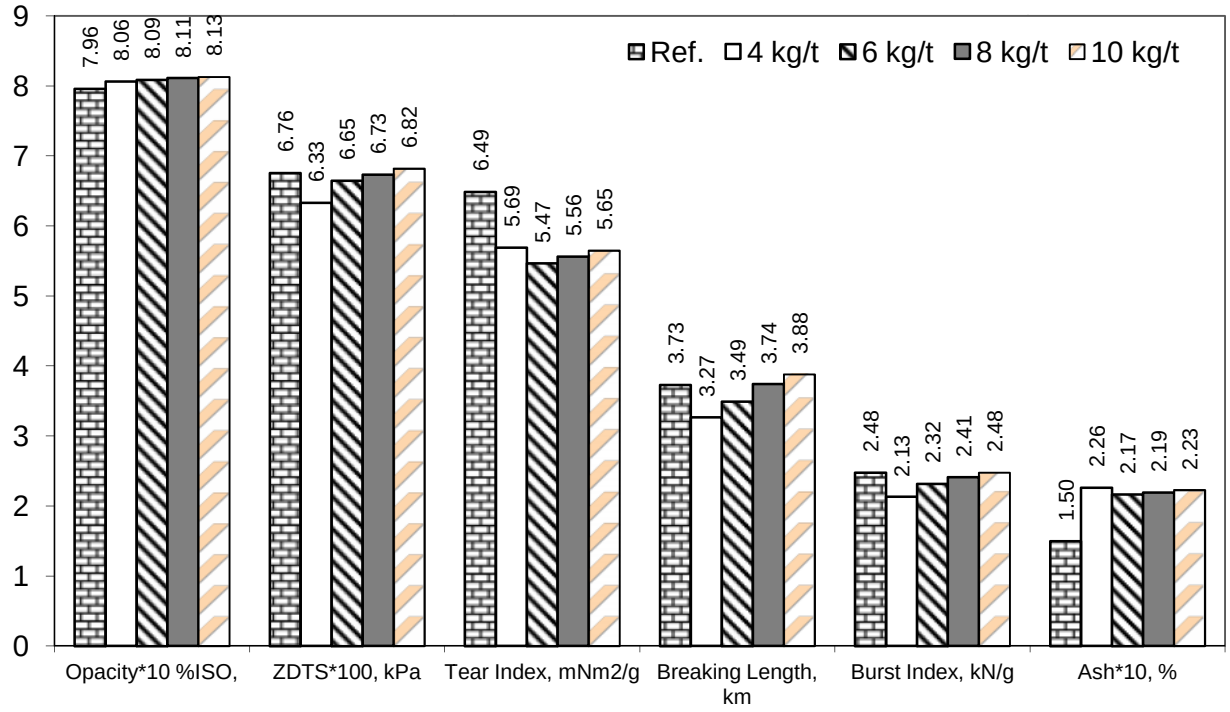

Figure 11: Effect of PS on properties of MHB pulp at 400 kg/t addition of talc

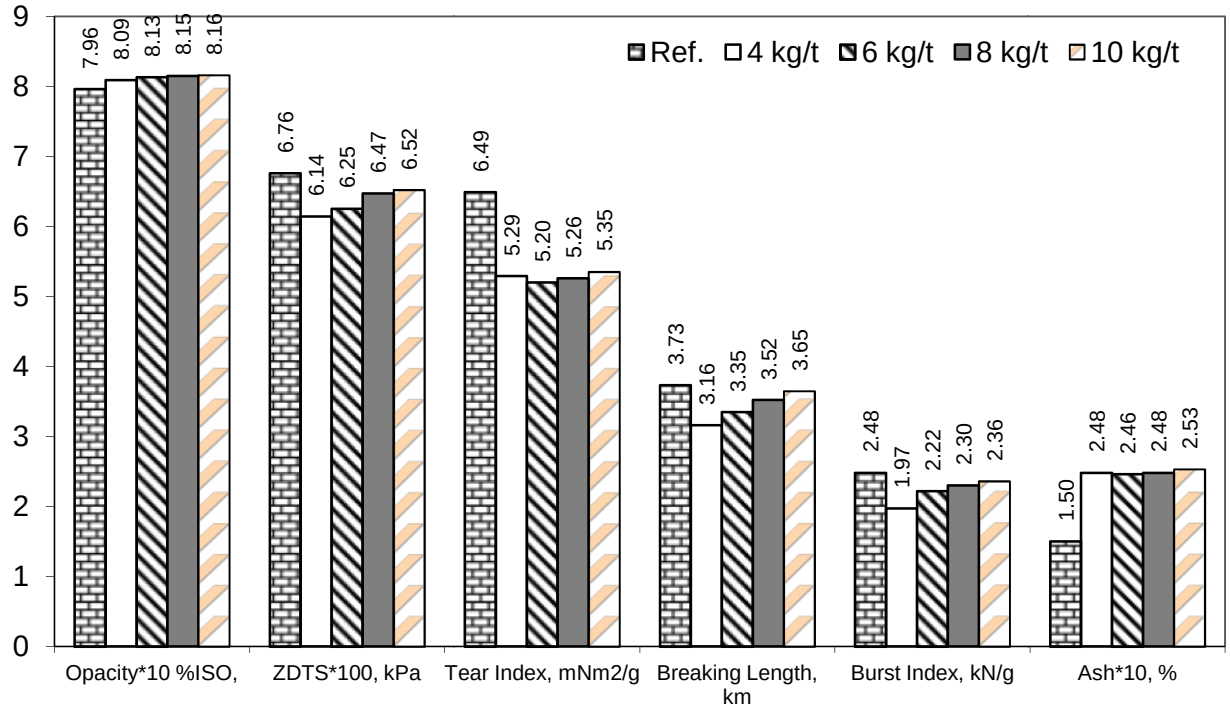

Figure 12: Effect of PS on properties of MHB pulp at 470 kg/t addition of talc

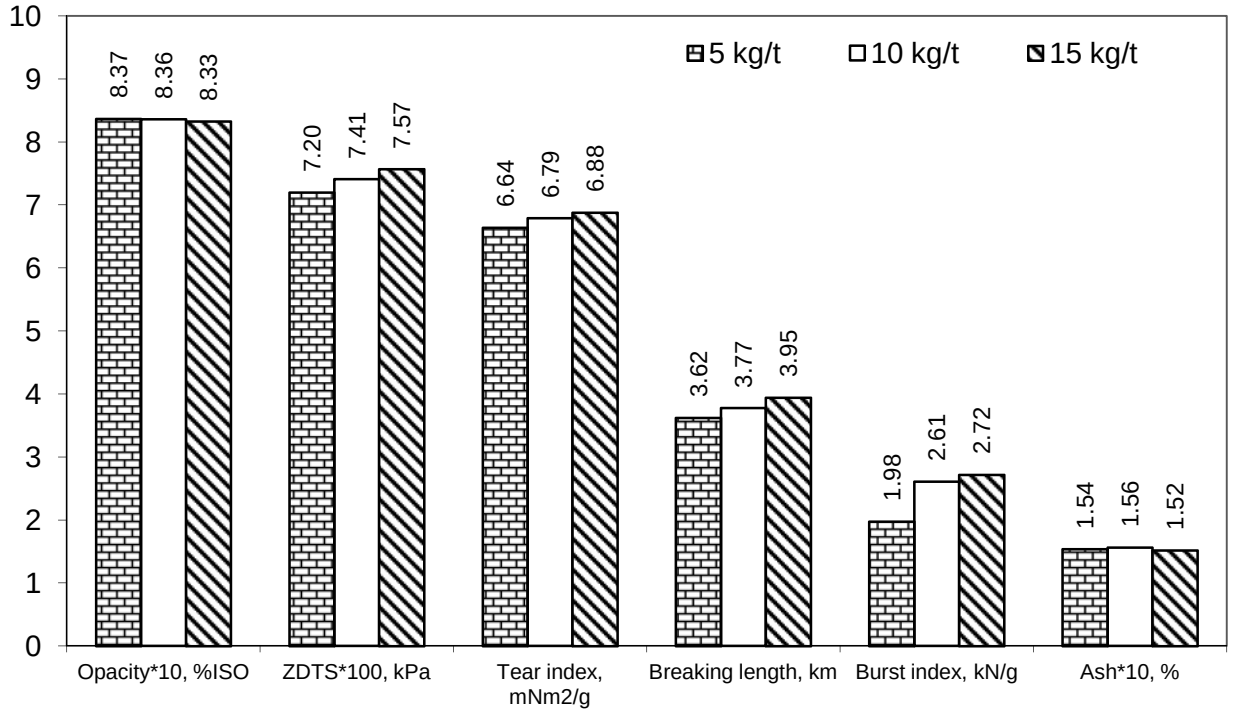

Figure 13: Effect of CS on properties of MHB pulp at 400 kg/t addition of GCC

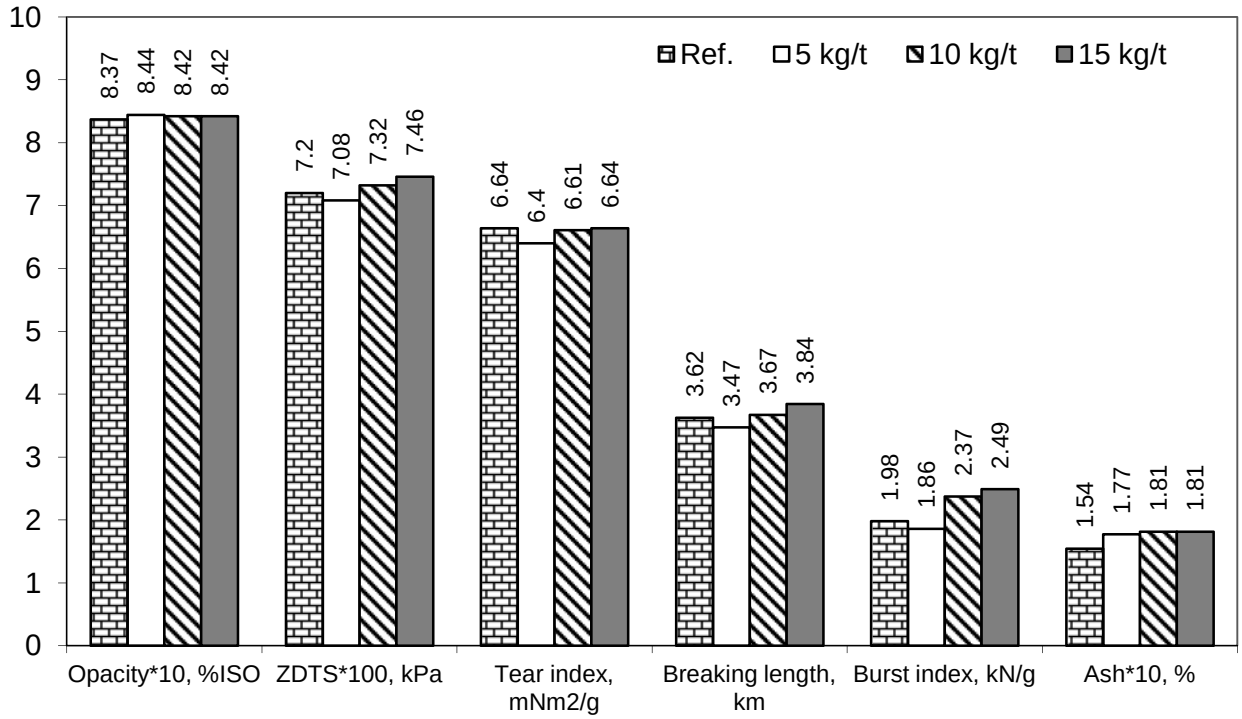

Figure 14: Effect of CS on properties of MHB pulp at 480 kg/t addition of GCC

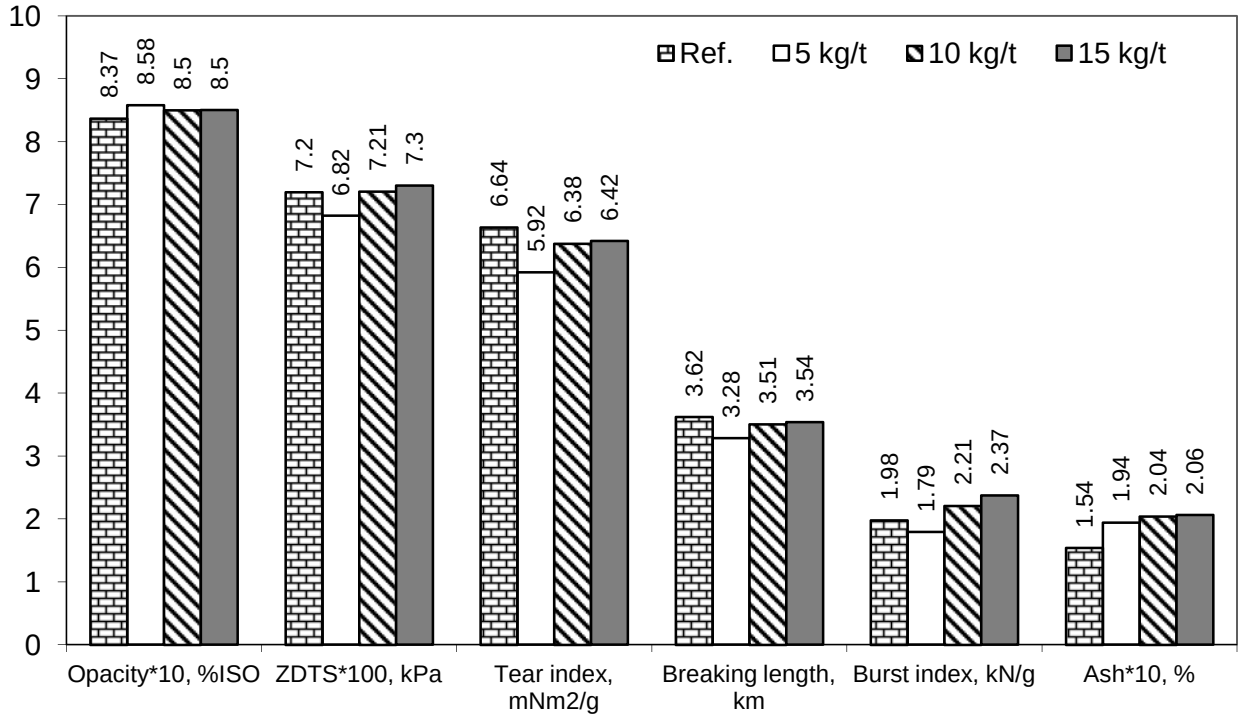

Figure 15: Effect of CS on properties of MHB pulp at 560 kg/t addition of GCC

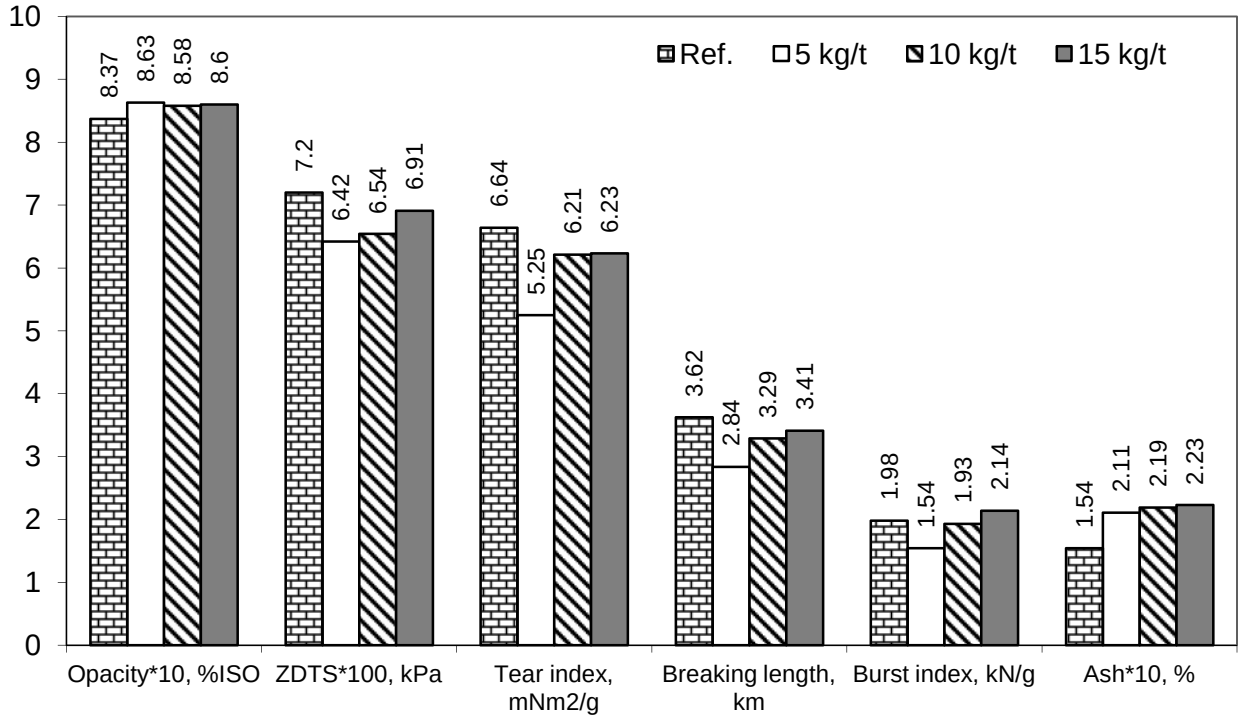

Figure 16: Effect of CS on properties of MHB pulp at 670 kg/t addition of GCC

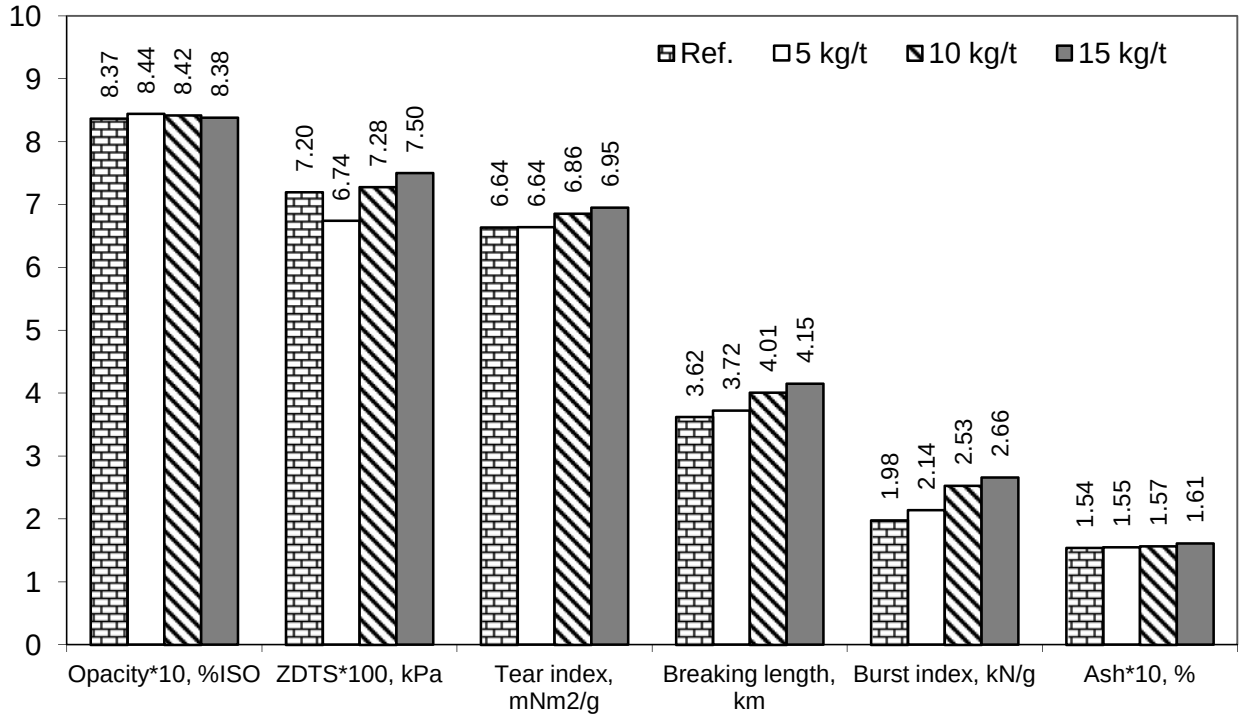

Figure 17: Effect of AS on properties of MHB pulp at 400 kg/t addition of GCC

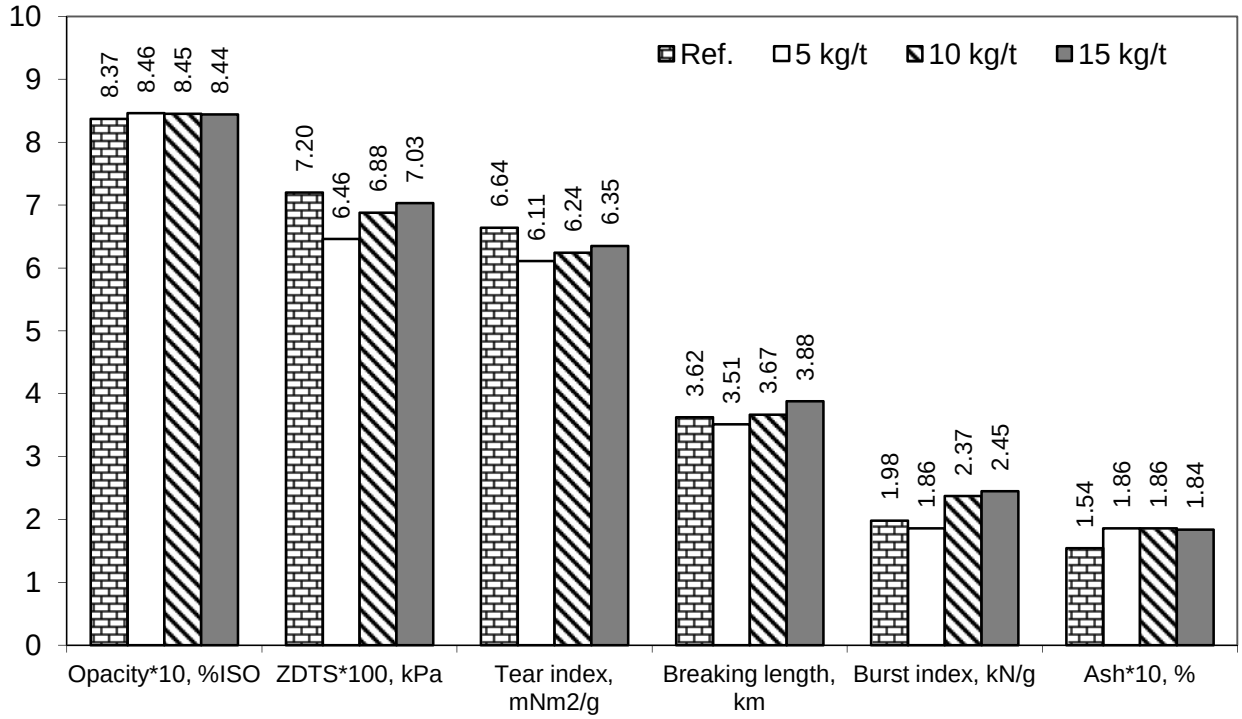

Figure 18: Effect of AS on properties of MHB pulp at 480 kg/t addition of GCC

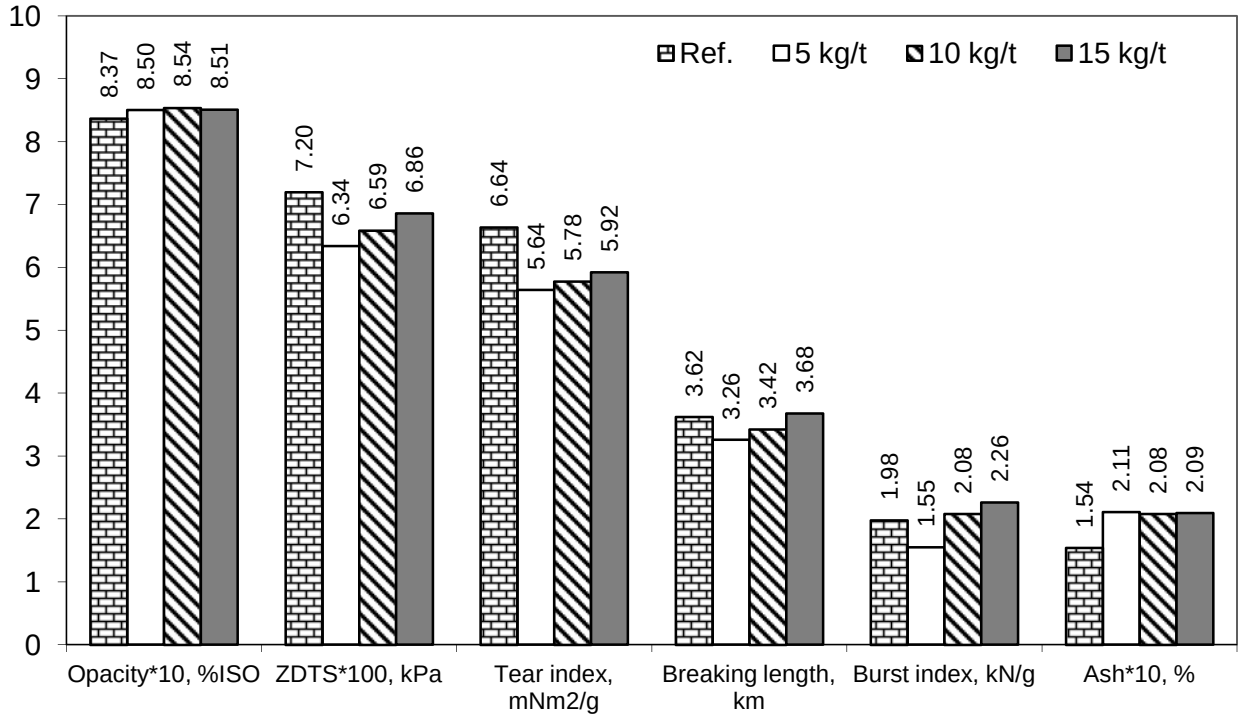

Figure 19: Effect of AS on properties of MHB pulp at 560 kg/t addition of GCC

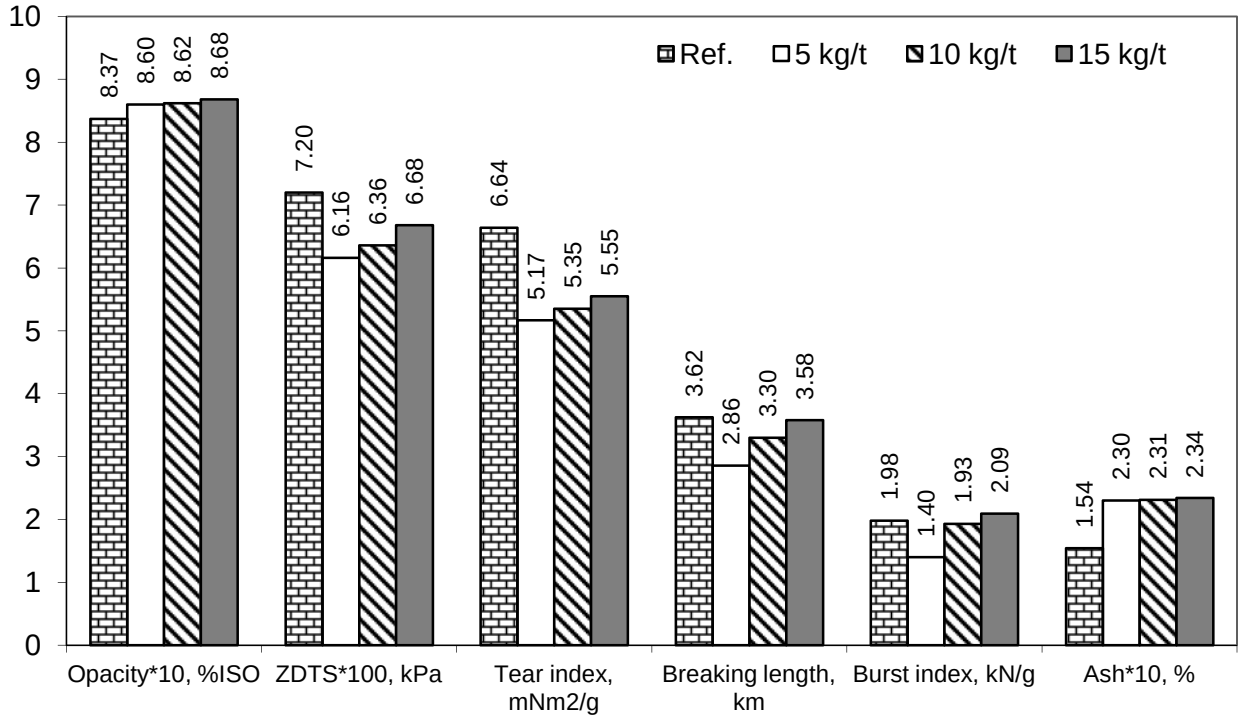

Figure 20: Effect of AS on properties of MHB pulp at 670 kg/t addition of GCC

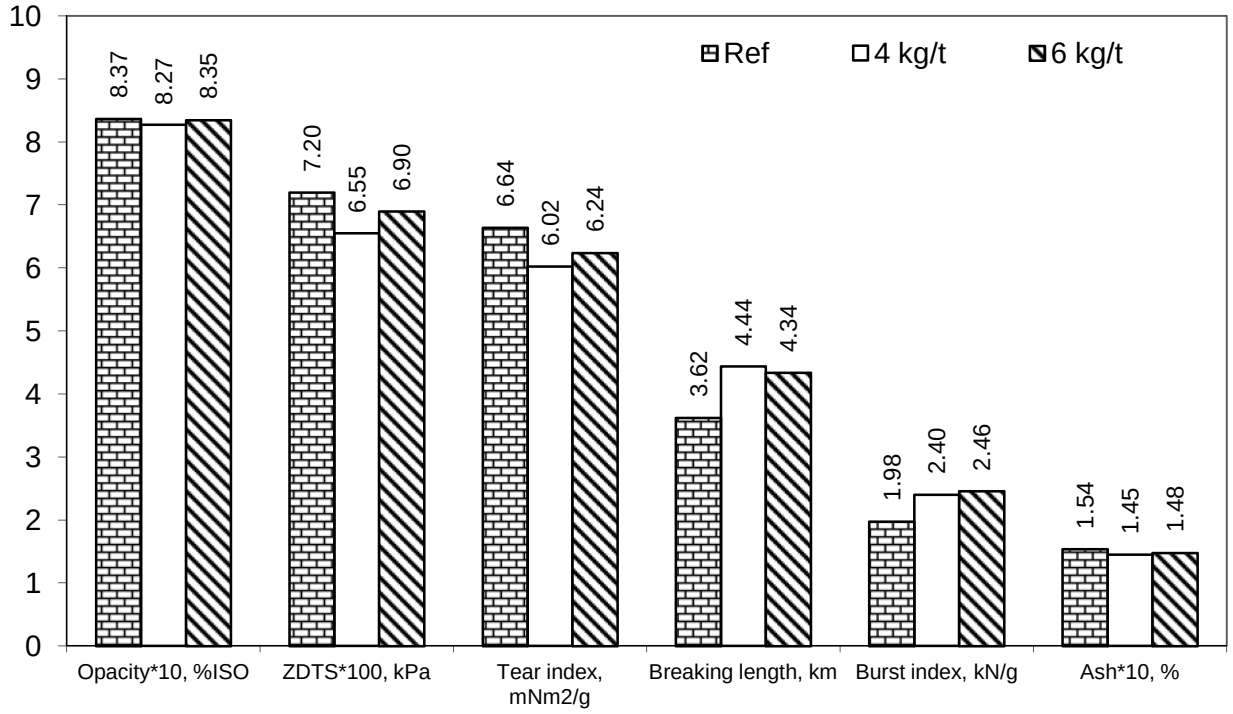

Figure 21: Effect of PS on properties of MHB pulp at 400 kg/t addition of GCC

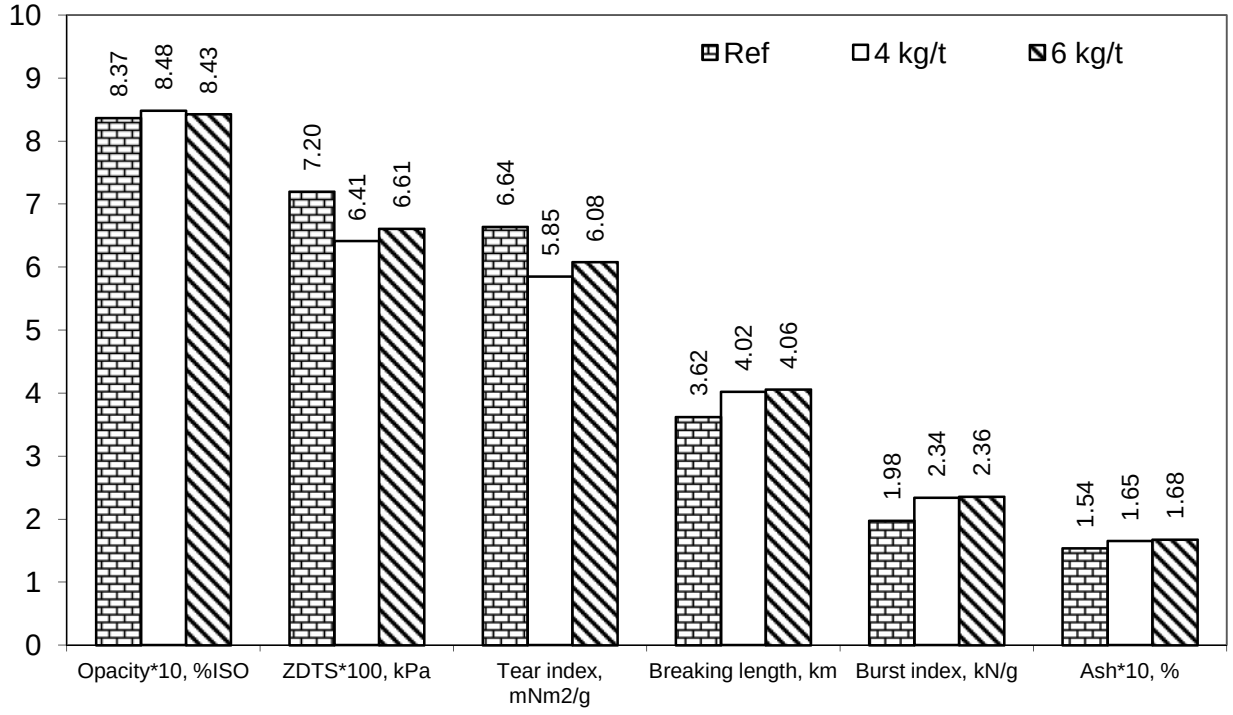

Figure 22: Effect of PS on properties of MHB pulp at 480 kg/t addition of GCC

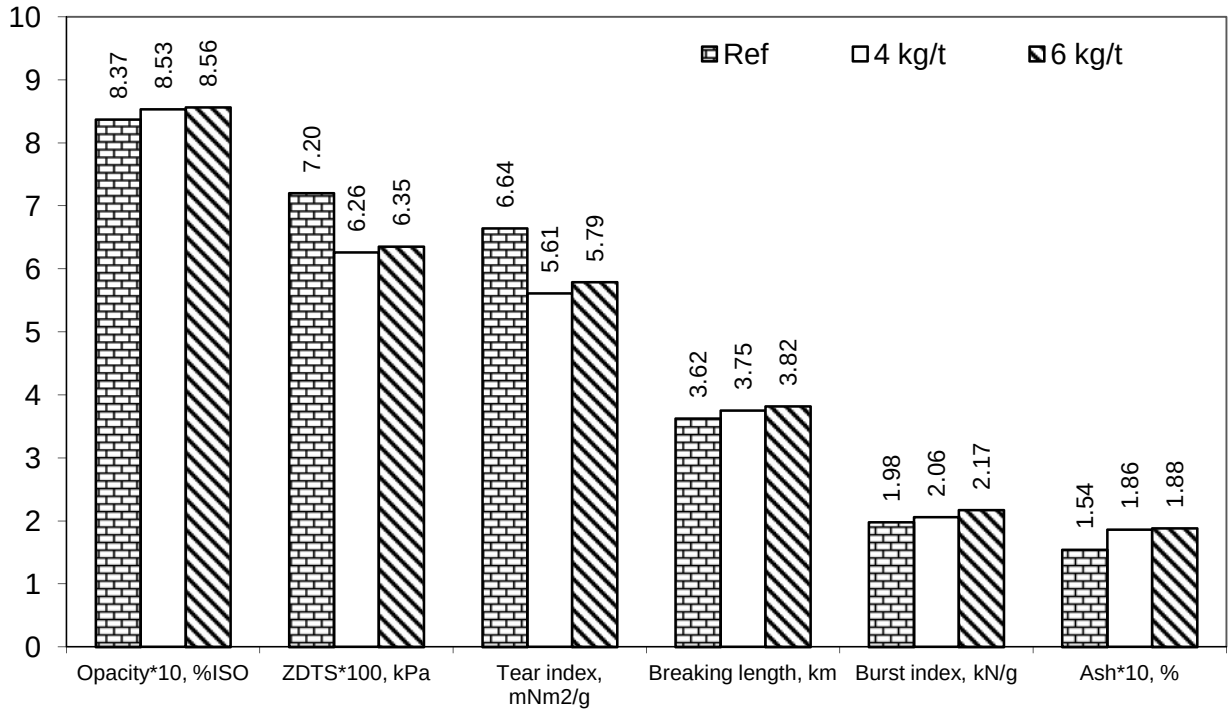

Figure 23: Effect of PS on properties of MHB pulp at 560 kg/t addition of GCC

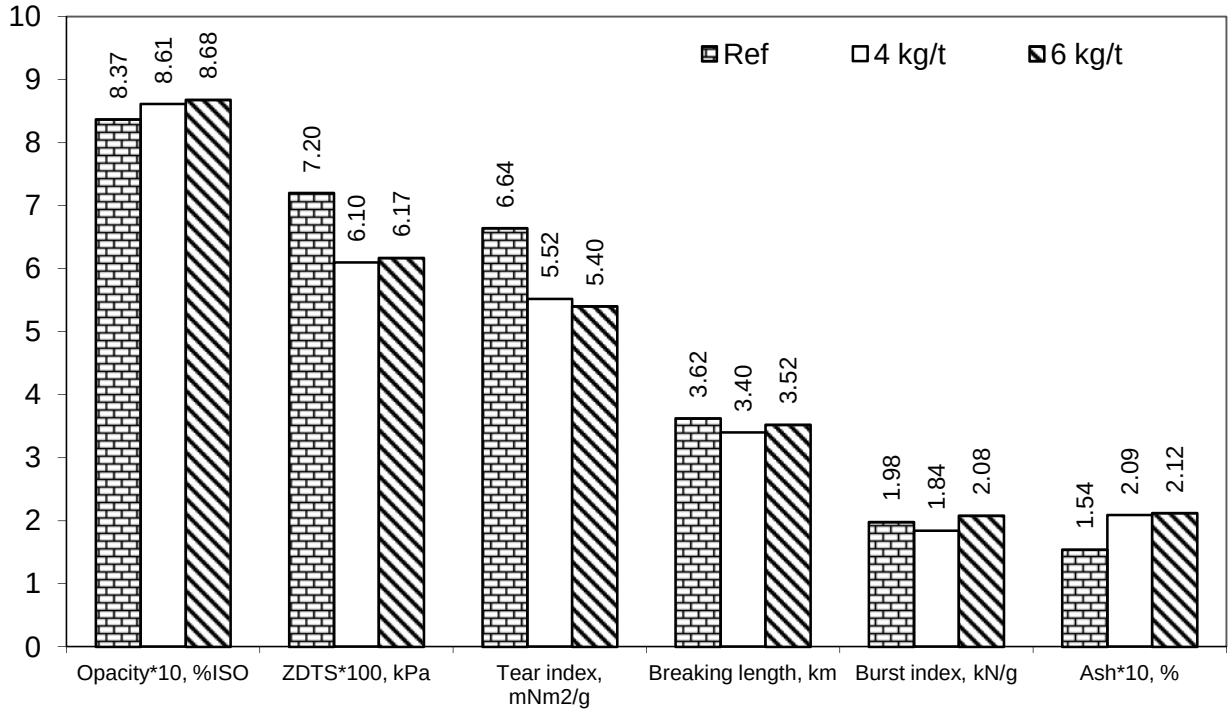

Figure 24: Effect of PS on properties of MHB pulp at 670 kg/t addition of GCC

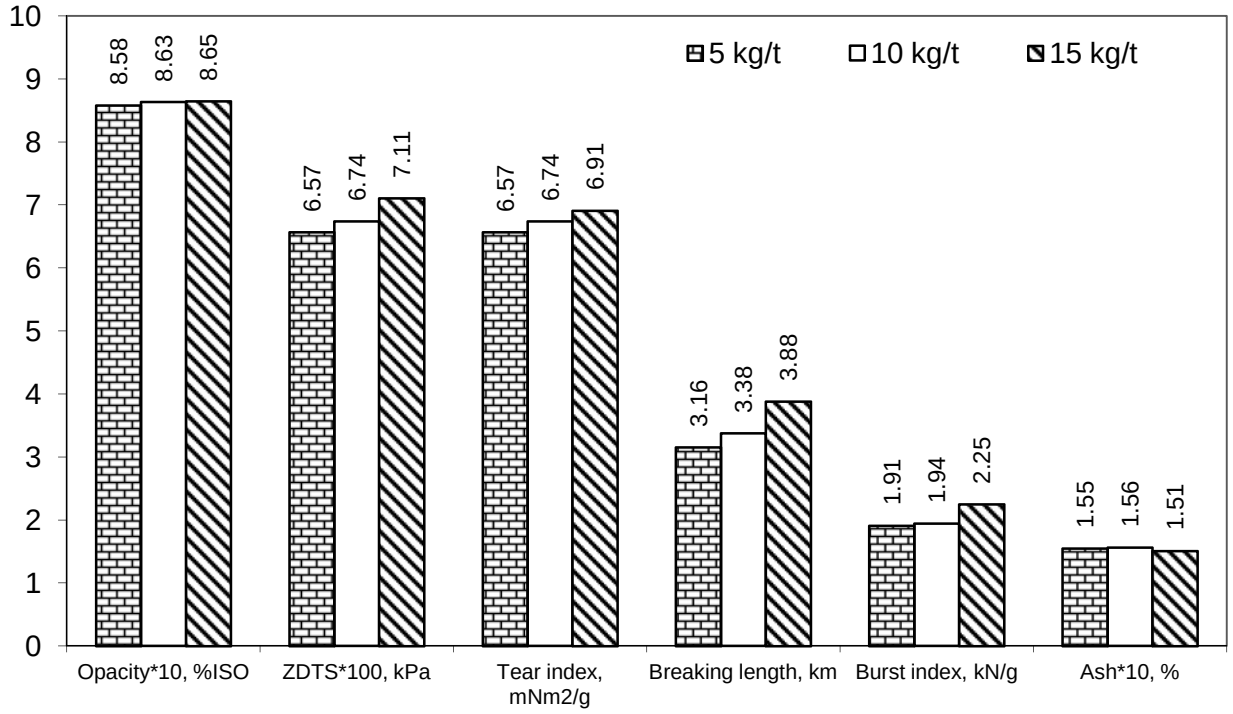

Figure 25: Effect of CS on properties of MHB pulp at 300 kg/t addition of PCC

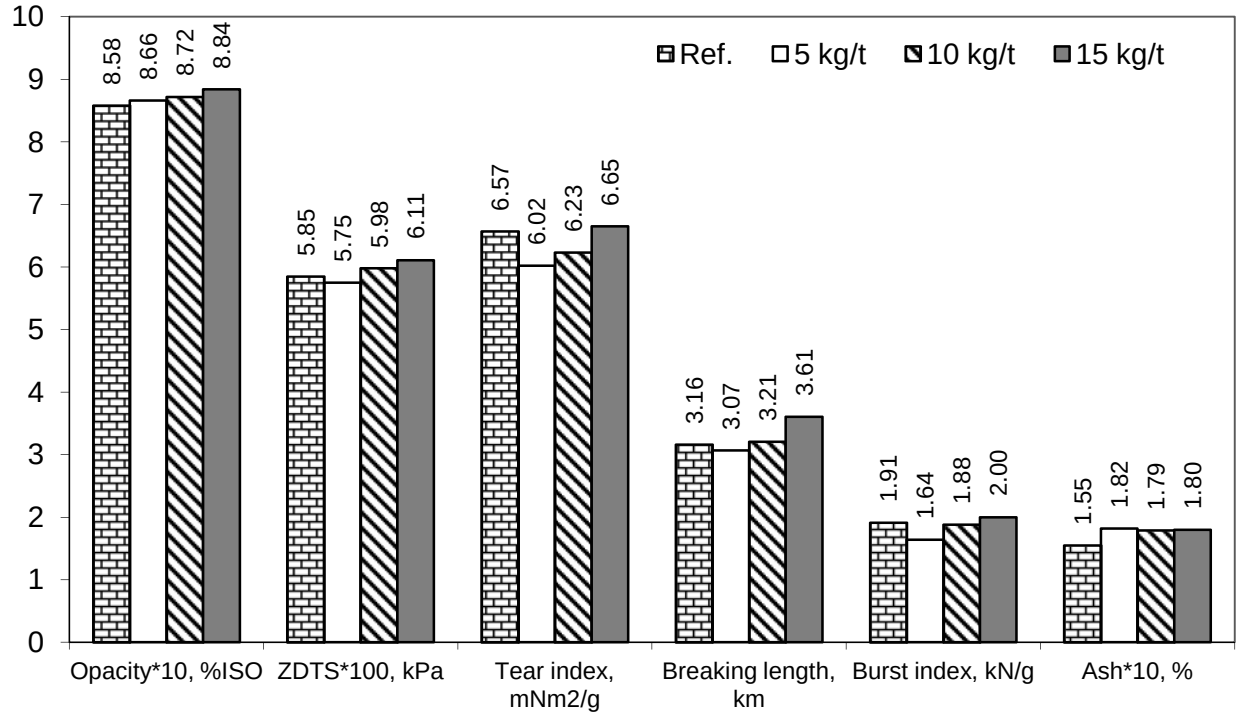

Figure 26: Effect of CS on properties of MHB pulp at 360 kg/t addition of PCC

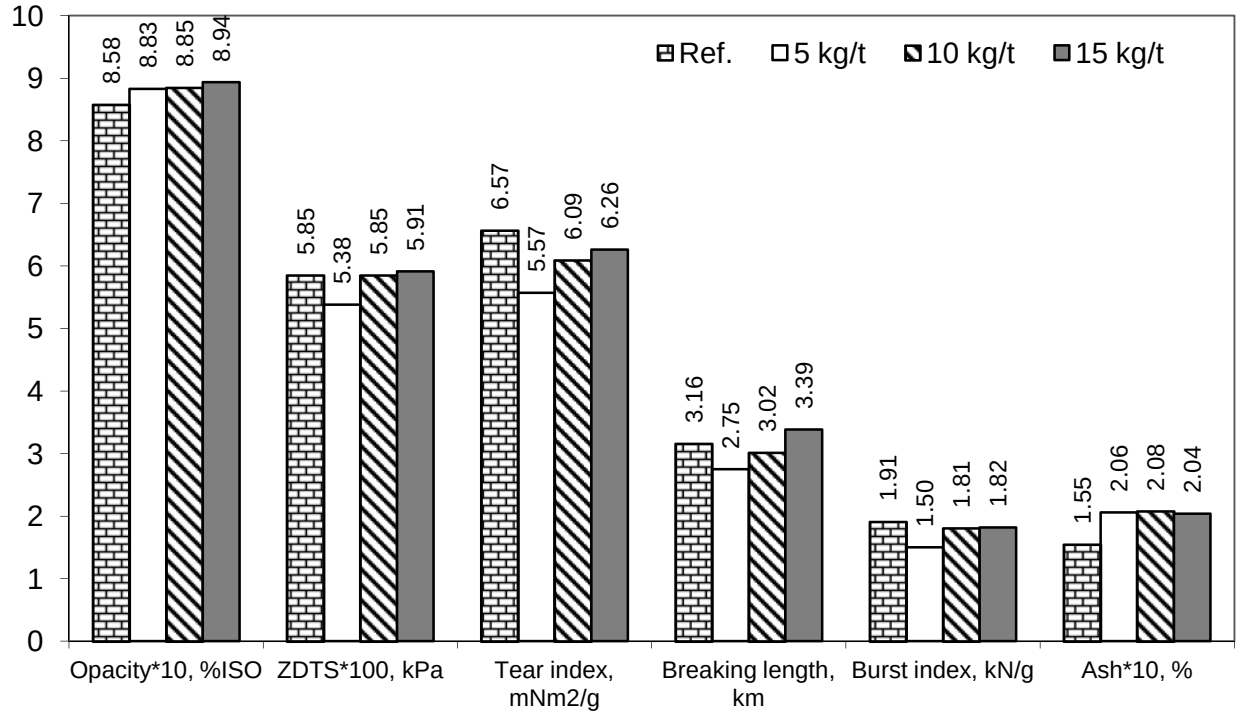

Figure 27: Effect of CS on properties of MHB pulp at 440 kg/t addition of PCC

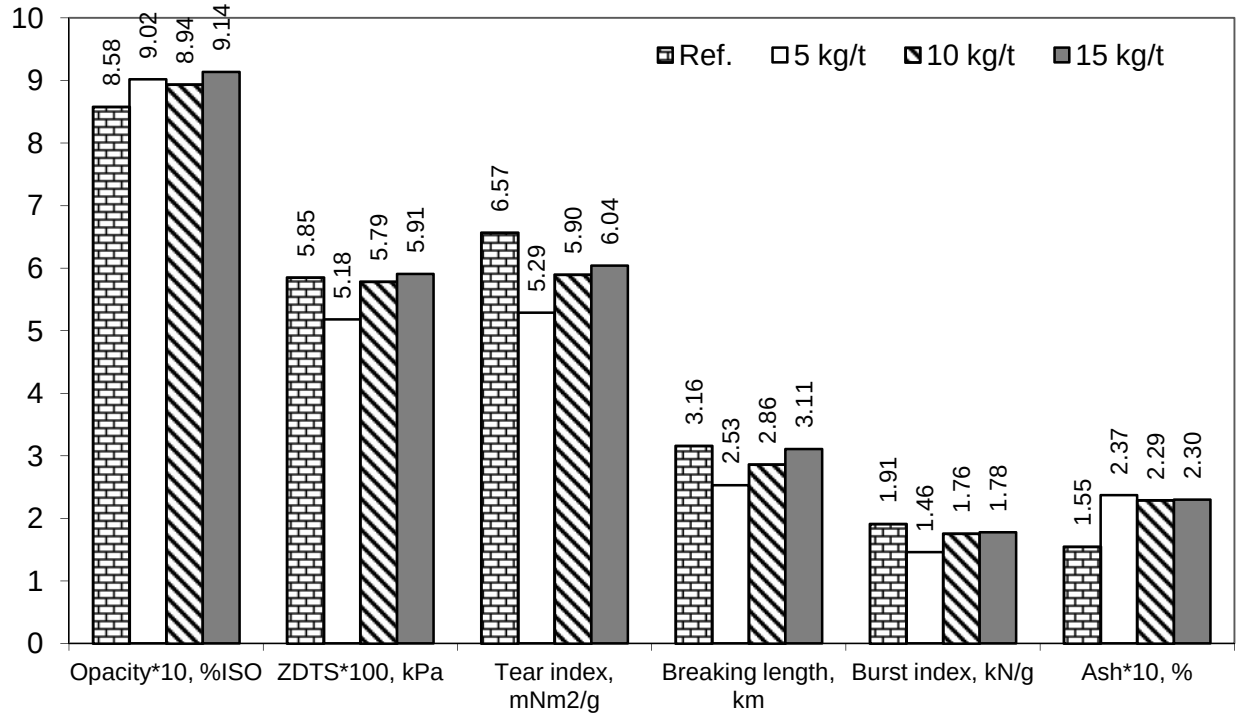

Figure 28: Effect of CS on properties of MHB pulp at 520 kg/t addition of PCC

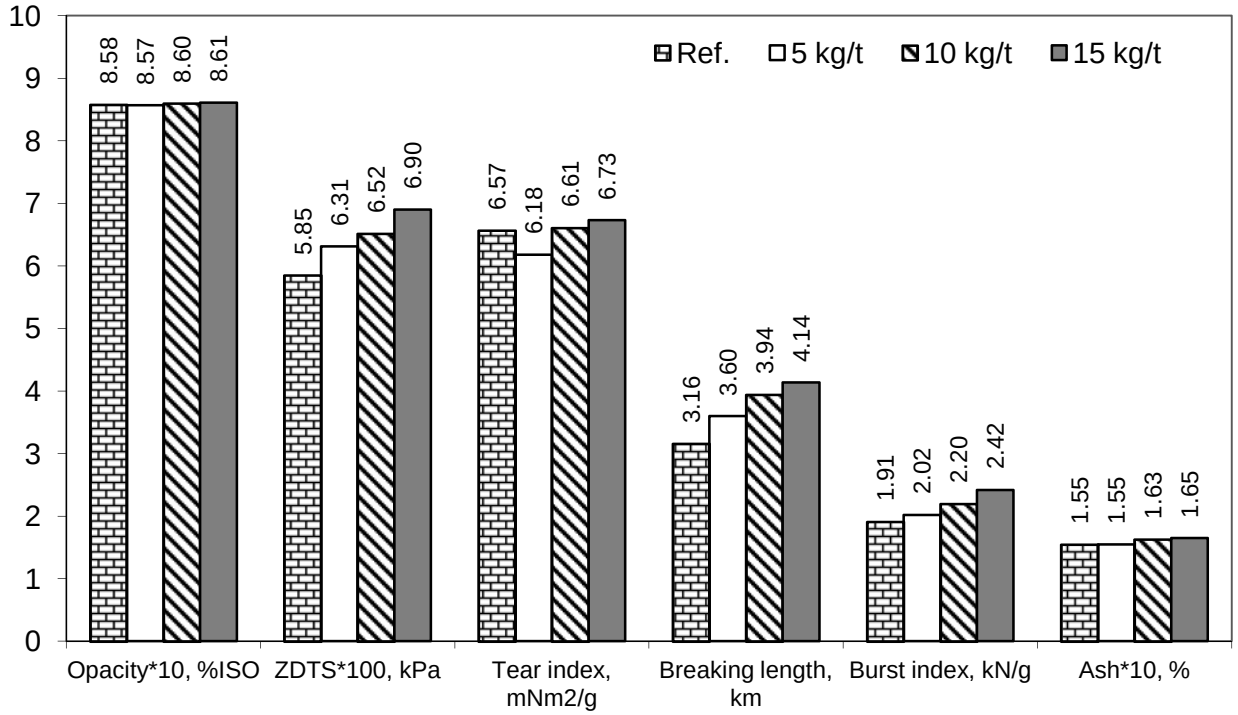

Figure 29: Effect of AS on properties of MHB pulp at 300 kg/t addition of PCC

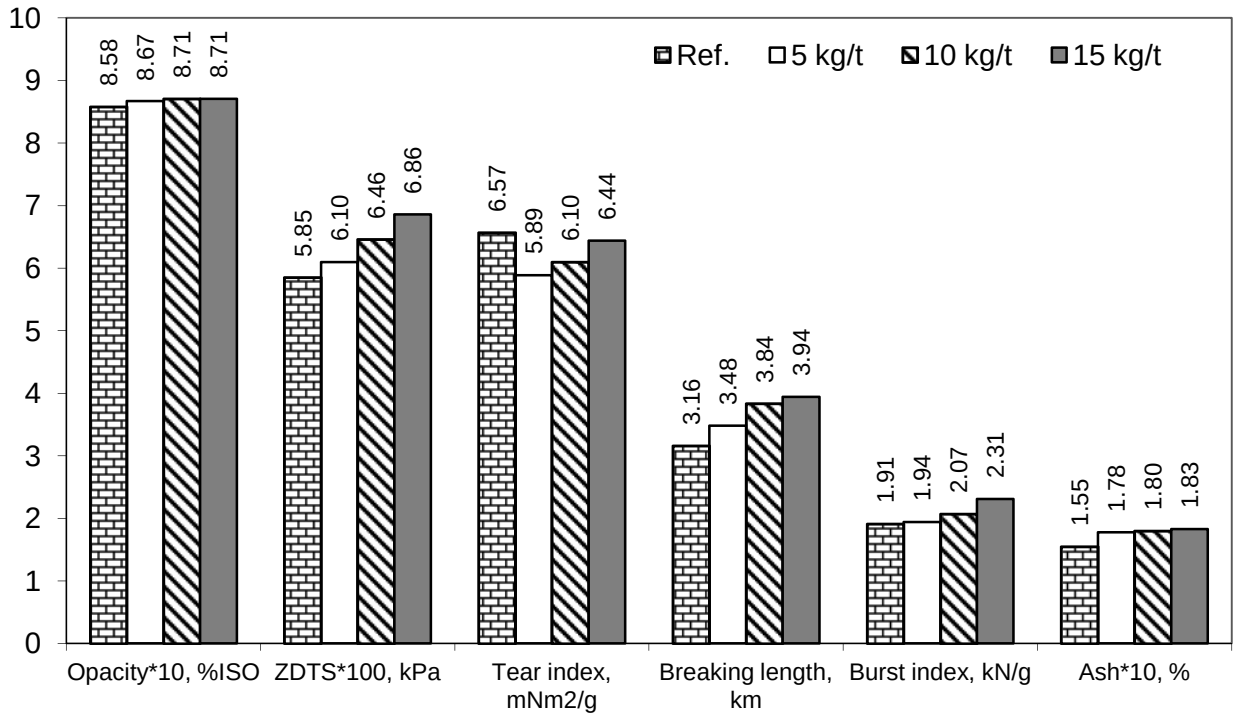

Figure 30: Effect of AS on properties of MHB pulp at 360 kg/t addition of PCC

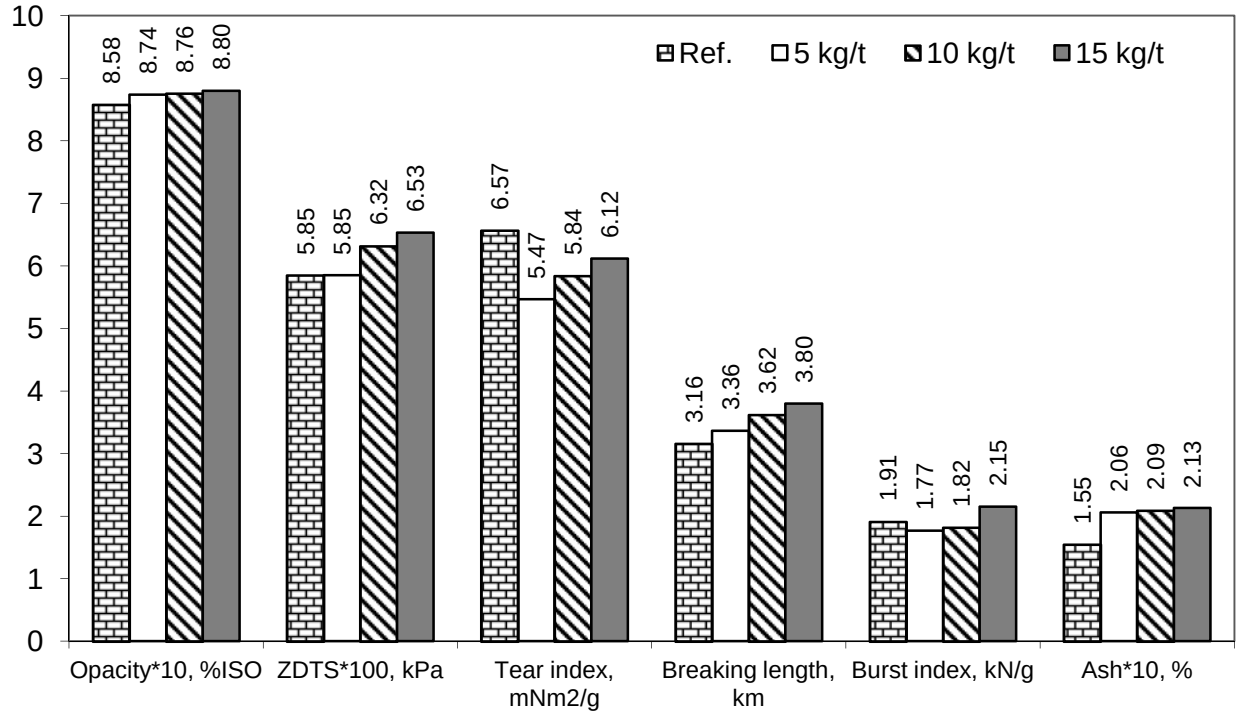

Figure 31: Effect of AS on properties of MHB pulp at 440 kg/t addition of PCC

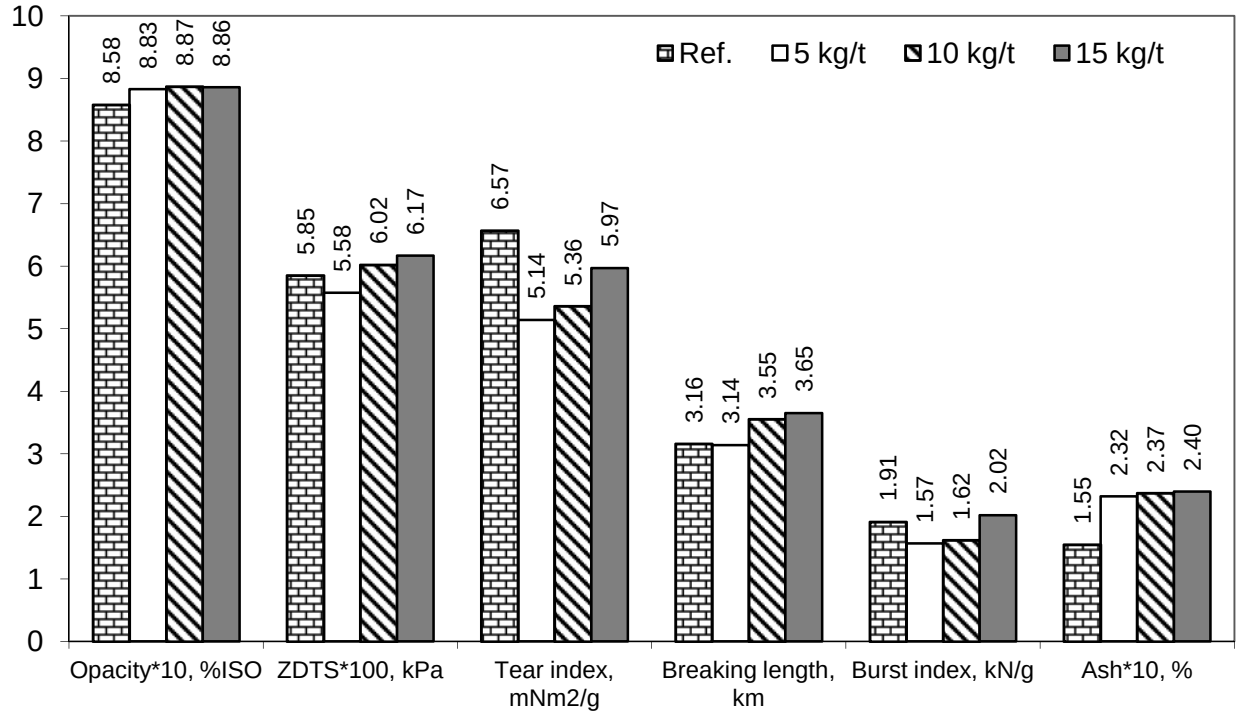

Figure 32: Effect of AS on properties of MHB pulp at 520 kg/t addition of PCC

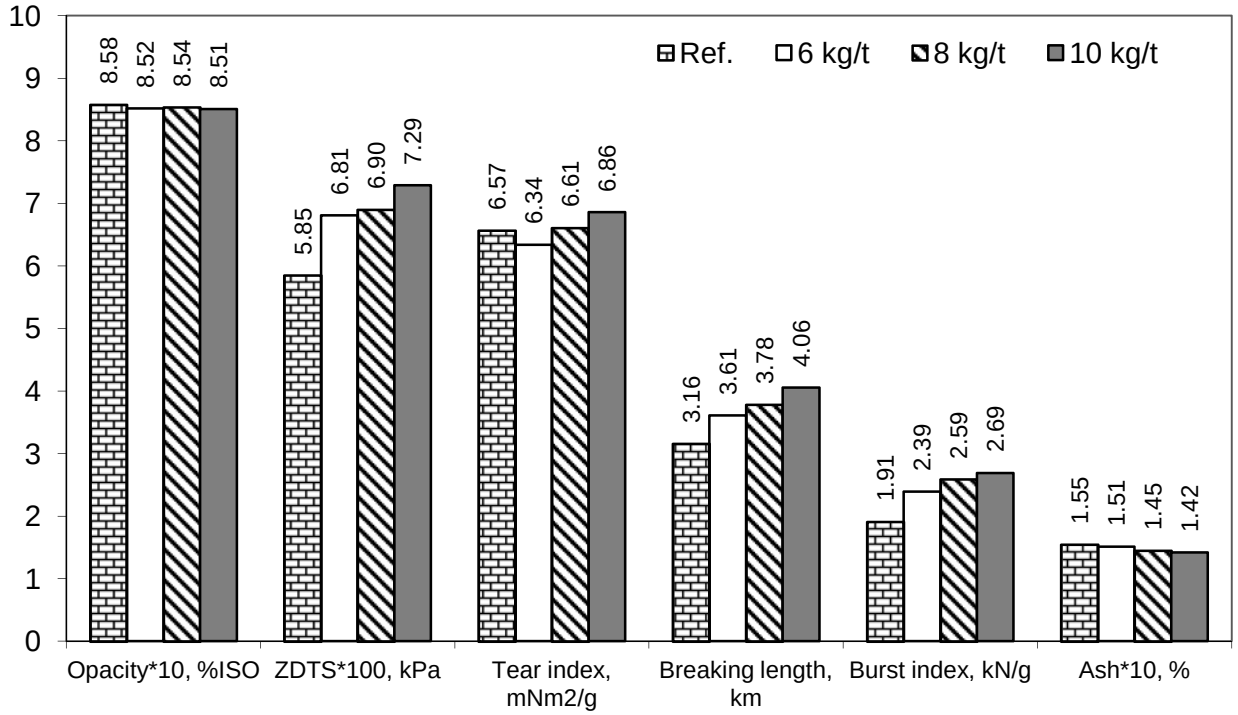

Figure 33: Effect of PS on properties of MHB pulp at 300 kg/t addition of PCC

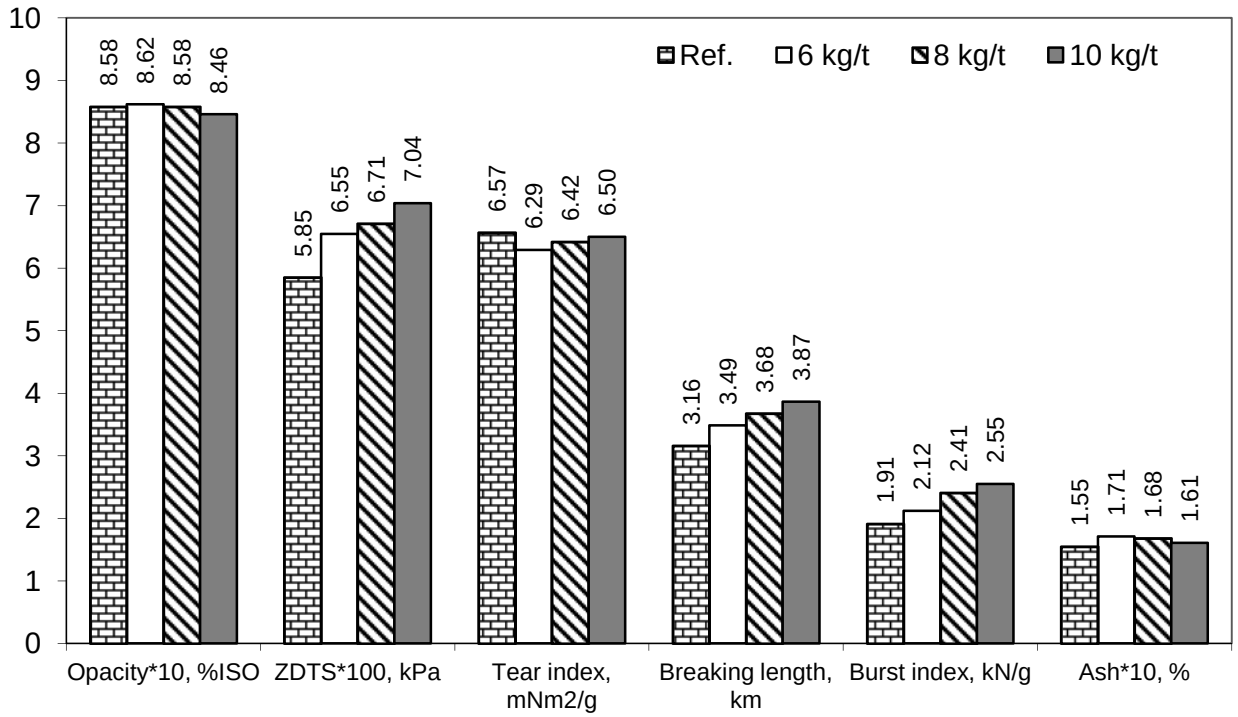

Figure 34: Effect of PS on properties of MHB pulp at 360 kg/t addition of PCC

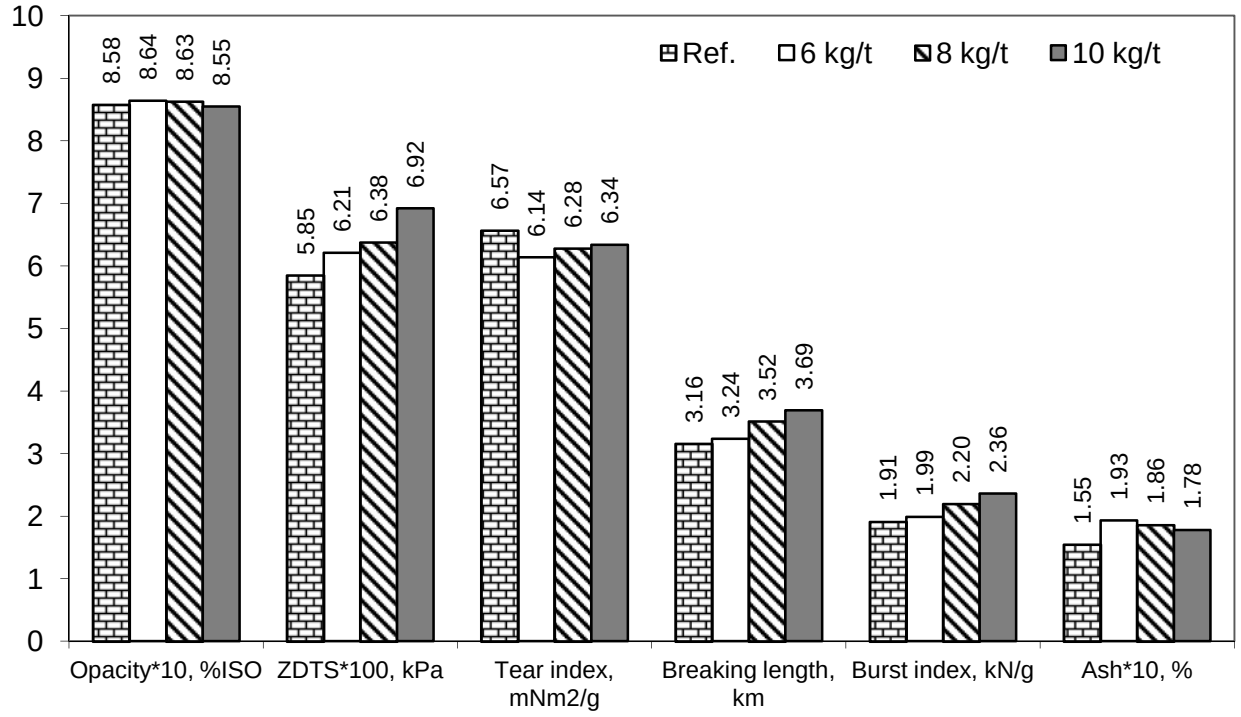

Figure 35: Effect of PS on properties of MHB pulp at 440 kg/t addition of PCC

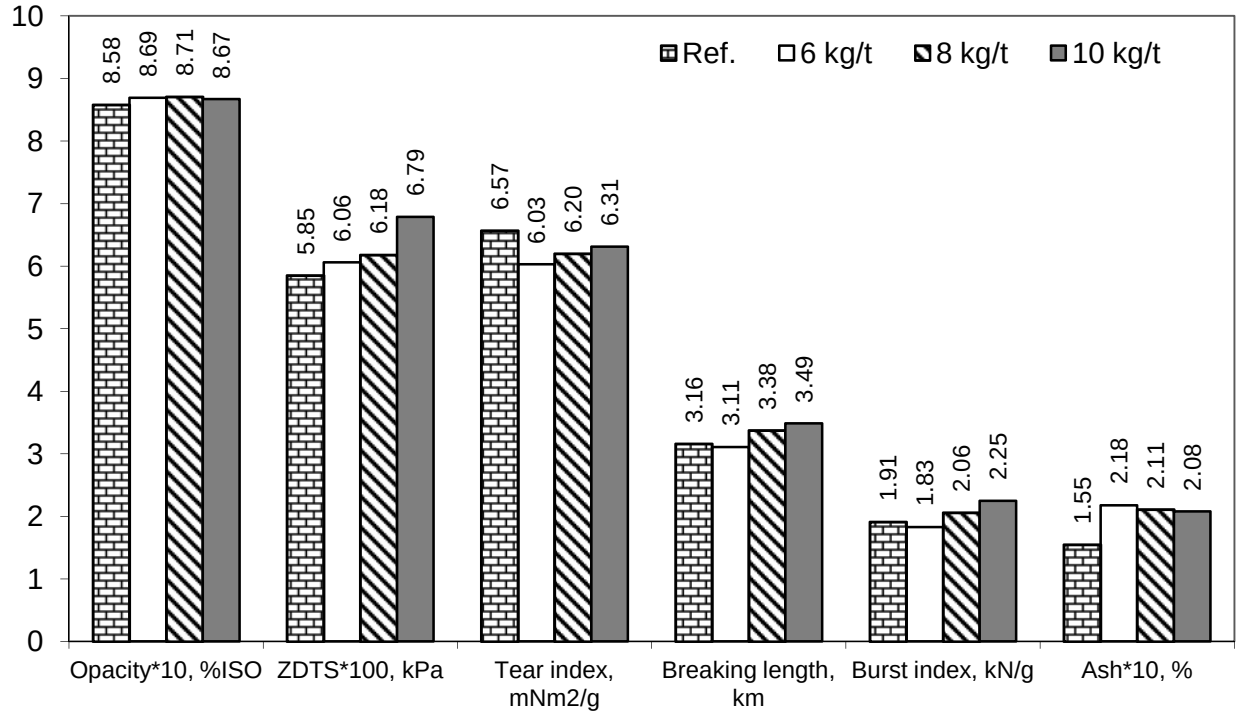

Figure 36: Effect of PS on properties of MHB pulp at 520 kg/t addition of PCC

CHAPTER – 2

Bleached Mixed Hardwood (MHW) Pulp

RESULTS & DISCUSSION

2.1. Effect of cationic strength additive and talc filler on paper

The properties of paper made with MHW pulp had almost similar trend as in case of MHB pulp. Similar to MHB furnish, in case of MHW pulp the zeta potential and charge demand decreased with increase of dose of CS (Table 38-40).

2.1.1. At 280 kg/t of Talc

At 280 kg/t addition of talc, the ash in paper was 16.4, 17.0 and 17.4% at 5, 10 and 15 kg/t dose of CS respectively i.e. increase in ash was linked with dose of CS. All strength properties increased with increase in CS dose (Figure 37).

2.1.2. At 340 kg/t of Talc

At 340 kg/t addition of talc, the ash in paper was 19.0, 19.7 and 20.2% at 5, 10 and 15 kg/t dose of CS i.e. increased by around 1% with increase in dose of CS from 5 to 15 kg/t. All strength properties were comparable to those of reference (16.4% ash with 5 kg/t dose of CS). Gain in opacity was around 1.5% (Figure 38).

2.1.3. At 400 kg/t of Talc

In this case also the ash in paper increased with increase in CS dose. Here, the strength properties of paper were slightly lower than those of reference. The gain in opacity was around 2% (Figure 39).

2.1.4. At 470 kg/t of Talc

Further increase in addition of talc to 470 kg/t showed a negative effect on all strength properties at all the CS dose (Figure 40).

It was concluded that the ash in paper could be increased from 16.4 to around 20% with CS with negligible effect on strength properties.

2.2. Effect of amphoteric strength additive and talc filler on paper

The FPAR with AS was a little higher than that with CS. The zeta potential and charge demand decreased with increase of AS dose (Table 41-43).

2.2.1. At 280 kg/t of Talc

The ash in paper was around 16.9, 17.4 and 17.7% at 5, 10 and 15 kg/t dose of AS respectively; 0.5-1.3% higher ash than that of reference at same talc addition level. All strength properties except ZDTS were higher than those of reference. Gain in opacity was around 1% (Figure 41).

2.2.2. At 340 kg/t of Talc

At 340 kg/t addition of talc, the ash in paper was 19.8, 20.5 and 20.8% at 5, 10 and 15 kg/t dose of AS respectively i.e. it has increased by around 1% with increase in CS dose from 5 to 15 kg/t. All strength properties except ZDTS were comparable or higher than those of reference. Gain in opacity was around 1.5% (Figure 42).

2.2.3. At 400 kg/t of Talc

In this case also the ash in paper increased with increase in AS dose. It was 22.9, 23.0 and 23.5% at 5, 10 and 15 kg/t dose of AS respectively. Here, breaking length and burst index were comparable to reference but tear index and ZDTS were lower by around 7 and 10% respectively. The gain in opacity was around 2% (Figure 43).

2.2.4. At 470 kg/t of Talc

Further increase in addition of talc to 470 kg/t showed a negative effect on all strength properties at all the AS doses (Figure 44).

It was concluded that the ash in paper could be increased from 16.4 to 20% with AS with negligible effect on strength properties.

2.3. Effect of polymeric strength additive and talc filler on paper

The FPAR with PS was slightly higher than that with CS and AS. The charge demand increased with increase of PS dose due to its anionic nature (Table 44-46).

2.3.1. At 280 kg/t of Talc

The ash in paper was 17.4, 17.7 and 17.9% at 5, 10 and 15 kg/t dose of PS respectively; 1.0-1.5% higher ash than that of reference at same talc addition level. All strength properties were comparable or higher than those of reference in spite of higher ash with the higher dose of PS. Gain in opacity was around 1% (Figure 45).

2.3.2. At 340 kg/t of Talc

At 340 kg/t addition of talc, the ash in paper was 20.6, 21.4 and 21.1% at 5, 10 and 15 kg/t dose of PS respectively i.e. ash in paper increased by around 1% with increase in PS dose from 5 to 15 kg/t. It was 1-1.5% higher than that with CS. Breaking length and burst index were comparable with those of reference whereas tear index and ZDTS were lower by around 4% each. Gain in opacity was around 1.3% at highest dose (Figure 46).

2.3.3. At 400 kg/t of Talc

At 400 kg/t addition of talc, the ash in paper was around 23.0%. Here, breaking length, burst index, tear index and ZDTS decreased by around 5, 7, 8 and 5% respectively. The gain in opacity was around 2% (Figure 47).

2.3.4. At 470 kg/t of Talc

Further increase in addition of talc to 470 kg/t showed a negative effect on all strength properties at all the PS doses (Figure 48).

It was concluded that the ash in paper could be increased from 16.4 to around 21% with PS without much affecting the strength properties.

2.4. Effect of cationic strength additive and GCC filler on paper

The strength properties decreased with increase in ash in paper, whereas optical properties increased at all the CS dose. The anionic zeta potential and cationic charge demand of pulp slurries decreased with increase in dose of GCC. Due to the cationicity of CS, the zeta potential and charge demand decreased with increase of CS dose. The FPAR of GCC filler (~60%) was comparatively lower than that of talc (Table 47-49).

2.4.1. At 400 kg/t of GCC

At 400 kg/t addition of GCC, the ash in paper increased from 16.7 to 17.5 and 17.8% with increase in dose of CS from 5 to 10 and 15 kg/t respectively. There was an increase in all strength properties with increase in CS dose. Opacity was comparable at all the CS doses (Figure 49). Double fold increased from 8 to 11 and 18 at 5, 10, and 15 kg/t dose of CS respectively (Table 47-49).

2.4.2. At 480 kg/t of GCC

At 480 kg/t addition of GCC, the ash in paper was around 19.5-20% at all CS doses. At 10-15 kg/t dose of CS, all strength properties were comparable to those of reference (16.7% ash with 5 kg/t dose of CS). The gain in opacity was around 1% (Figure 50).

2.4.3. At 560 kg/t of GCC

At 560 kg/t addition of GCC, the ash in paper was around 21.5% at all CS doses. All strength properties except tear index were comparable at 15 kg/t dose of CS to those of reference. The drop in tear index was around 7.5% (Figure 51).

2.4.4. At 670 kg/t of GCC

At 670 kg/t addition of GCC, the ash in paper varied from 23.2 to 24.3%. The ash in paper could be increased by about 1% with the increased dose of CS from 5 to 10 or 15 kg/t. All strength properties decreased as compared with reference (Figure 52).

It was concluded that the ash in paper could be increased from 15 to 18% with 10-15 kg/t dose of CS or to 21% with a little drop in tear index. The latter might be compensated by reducing the degree of refining.

2.5. Effect of amphoteric strength additive and GCC filler on paper

The strength properties decreased and optical properties increased with increase in ash content of paper at all the AS doses. The cationic charge demand of pulp slurries decreased with increase in dose of GCC. Similar to CS, the charge demand decreased with increase of CS dose. The bulk of paper made with GCC was slightly higher than that with talc (Table 50-52).

2.5.1. At 400 kg/t of GCC

At 400 kg/t addition of GCC, the ash in paper increased from 16.9 to 17.9% against 16.7% of reference (16.7% ash with 5 kg/t dose of CS) with 15 kg/t dose of CS. There was an increase in all strength properties with increase in AS dose. At 10-15 kg/t dose of AS, almost all strength properties were higher than those of reference. Opacity was also increased by 1% due to increase in ash content (Figure 53).

2.5.2. At 480 kg/t of GCC

At 480 kg/t addition of GCC, the ash in paper was approximately 20% at all AS doses. Strength properties increased with increase in AS dose. At 15 kg/t dose of AS, burst index and tear index were higher whereas breaking length and ZDTS were comparable to those of reference. The gain in opacity was 1.5-2% (Figure 54).

2.5.3. At 560 kg/t of GCC

At 560 kg/t addition of GCC, the ash in paper was around 22% at all doses of AS. Here, all strength properties except ZDTS were a little lower than those of reference. Gain in opacity was around 3% (Figure 55).

2.5.4. At 670 kg/t of GCC

At 670 kg/t addition of GCC, the ash in paper varied from 24.1 to 25.3% with increasing dose of AS. At this ash level, all strength properties were lower than those of reference even at highest dose of AS (Figure 56).

Here, it was concluded that the ash in paper could be increased from 16.7 to 20% with10-15 kg/t dose of AS.

2.6. Effect of cationic strength additive and PCC filler on paper

With increase in the dose of PCC, the strength properties decreased whereas optical properties increased at all doses of CS. The decrease in strength properties in case of PCC was higher than that in case of talc and GCC. It might be due to the fact that PCC has a higher percentage of finer particles and accordingly higher surface area. As a result, the bulk of paper increased with the use of PCC as compared to talc and GCC. Optical properties viz. brightness, whiteness, opacity, and scattering coefficient increased significantly as compared to those with talc and GCC (Table 53-55).

2.6.1. At 300 kg/t of PCC

At 300 kg/t addition of PCC, the ash in paper at all CS doses was around 15-16%. There was an increase in almost all strength properties with increase in CS dose (Figure 57).

2.6.2. At 360 kg/t of PCC

At 360 kg/t addition of PCC, the ash in paper was approximately 18% at all CS doses. At 10-15 kg/t dose of CS, almost all strength properties were comparable with those of reference (15% ash with 5 kg/t dose of CS). In case of PCC, ash in paper could be increased from 15 to 18% with 10-15 kg/t dose of CS without affecting the strength properties. The opacity increased by ~2% due to increase in ash content from 15 to 18% (Figure 58).

2.6.3. At 440 kg/t of PCC

At 440 kg/t addition of PCC, the ash in paper was approximately 21.5% at all CS doses. At 15 kg/t dose of CS, all strength properties were comparable to those in case of reference except tear index which decreased from 5.58 to 5.30 mNm^2/g i.e. around 5%. The increase in opacity was around 3% (Figure 59).

2.6.4. At 520 kg/t of PCC

Further increase in the dose of PCC to 520 kg/t increased the ash in paper to around 23.5%. At this ash level also, there was no much reduction in strength properties except tear index as compared with reference. The drop in tear index, ZDTS, breaking length and burst index were 7, 2, 5 and 5% respectively (Figure 60).

It was concluded that the ash could be increased from 15 to 21% with 15 kg/t dose of CS without affecting strength properties. It also improved optical properties of paper including opacity and scattering coefficient.

2.7. Effect of amphoteric strength additive and PCC filler on paper

Similar to results in case of CS, the strength properties decreased with increase in ash in paper whereas optical properties increased at all doses of AS. The cationic charge demand of pulp slurries decreased with increase in dose of PCC. Due to cationic nature of AS, the zeta potential and charge demand decreased with its increased dose. The bulk of paper made with PCC was higher than that with talc and GCC (Table 56-58).

2.7.1. At 300 kg/t of PCC

At 300 kg/t addition of PCC, the ash in paper was approximately 15.5-16.5% at all doses of AS, which increased with increase in AS dose. There was an increase in all strength properties with increase in AS dose. Even at 5 kg/t dose of AS, all strength properties were higher than those of reference (15% ash with 5 kg/t dose of CS) (Figure 61).

2.7.2. At 360 kg/t of PCC

At 360 kg/t addition of PCC, the ash in paper was approximately 18% at all AS doses. At 5 kg/t dose of AS, all strength properties except tear index were comparable to those of reference. Increasing AS dose to 10 kg/t increased the strength properties of paper. The tear index was also comparable at this dose. From figure 62 it is evident that in case of PCC, ash in paper could be increased from 15 to 18% with 5-10 kg/t of AS without affecting the strength properties and with 2% gain in opacity.

2.7.3. At 440 kg/t of PCC

At 440 kg/t addition of PCC, the ash in paper was approximately 21.5% at all doses of AS. Except tear index, all strength properties of paper at this ash and AS (10 kg/t) dose were higher than those of reference. The drop in tear index was around 7%. Increasing dose of AS to 15 kg/t, the drop in tear index was 4.5% while other strength properties further improved. Here, ash in paper could be increased from 15 to 21% with 10-15 kg/t of AS with a little compromise in tear index (Figure 63). The tear index might be compensated with adjustment in refining.

2.7.4. At 520 kg/t of PCC

At 520 kg/t addition of PCC, the ash in paper was around 23.5-24% at all doses of AS. At this ash level and 15 kg/t dose of AS, all strength properties of paper except tear index were either higher or comparable to those of reference. The tear index dropped by 5.4% (Figure 64).

It was concluded that the ash in paper could be increased from 15 to 18% with 10 kg/t of AS and to 21-23% with 15 kg/t of AS without affecting strength properties. A little mild refining might compensate the tear index.

2.8. Effect of polymeric strength additive and PCC filler on paper

The cationic charge demand of pulp slurries decreased with increase in dose of PCC. Due to anionicity of PS, the zeta potential and charge demand increased with the increased dose of PS (Table 59-61).

2.8.1. At 300 kg/t of PCC

At 300 kg/t addition of PCC, the ash in paper decreased a little with PS. Similarly, FPAR decreased from 66.5 (reference) to 63.5% with PS. Though, strength properties were higher at all doses of PS as compared with reference (15% ash with 5 kg/t dose of CS) (Figure 65).

2.8.2. At 360 kg/t of PCC

At 360 kg/t addition of PCC, ash in paper and FPAR decreased with increase in dose of PS. The ash reduced from 18.2 to 17.1 and 16.0% with increase in dose of PS from 6 to 8 and 10 kg/t respectively. The corresponding ash in case of CS and AS was around 18%. At 6 kg/t of PS, all strength properties were comparable to those of reference. The strength properties of paper increased with increase in dose of PS but at reduced ash content (Figure 66).

2.8.3. At 440 kg/t of PCC

At 440 kg/t addition of PCC also, ash in paper and FPAR decreased with increase in dose of PS. The ash reduced from 20.1 to 19.6 and 19.1% with increased dose of PS from 6 to 8 and 10 kg/t respectively. The corresponding ash in case of CS and AS was around 21.5%. At 6 kg/t dose of PS, the burst index and breaking length were higher but tear index and ZDTS were lower than those of reference (Figure 67).

2.8.4. At 520 kg/t of PCC

Similar to previous cases at 520 kg/t addition of PCC also, ash in paper and FPAR decreased with increase in dose of PS. The ash reduced from 22.3 to 21.4 and 20.6% with increased dose of PS from 6 to 8 and 10 kg/t respectively. The corresponding ash in case of CS and AS was around 23.5%. At this ash level, the drop in tear index and ZDTS increased further whereas breaking length and burst index were comparable to those of reference (Figure 68).

It was concluded that the ash could be increased from 15 to 18% with 6 kg/t of PS without affecting strength properties.

Table 38: Properties of MHW pulp with talc and cationic strength additive at 5 kg/t

Talc addition, %	Blank*	28	34	40	47
Retained ash, %	0.62	16.4	19.0	22.2	24.7
FPAR, %	-	74.5	74.9	77.7	77.3
CSF, ml	430	485	495	500	510
Streaming potential, mV	-240	-265	-270	-280	-287
Charge demand, µeq/L	10.0	5.6	5.8	6.1	6.3
Zeta potential, mV	-24.4	-13.7	-14.4	-15.6	-16.4
Conductivity, mS	0.433	0.429	0.433	0.428	0.435
Bulk, cc/g	1.36	1.32	1.32	1.30	1.28
Breaking length, m	5251	4694	4237	3743	3529
Burst index, kN/g	3.68	2.68	2.58	2.22	2.01
Tear index, $mN.m^2/g$	7.11	5.73	5.30	5.21	5.05
Double fold, no.	27	16	14	11	10
ZD tensile strength, kPa	788	797	730	727	652
Bending stiffness, mN.m	0.238	0.179	0.176	0.172	0.157
Air permeance, Gurley s	15.4	15.8	13.0	12.3	11.1
Bendtsen roughness, mL/min	122	140	138	138	128
Brightness, %ISO	84.6	84.3	84.6	84.9	85.2
Opacity, %ISO	77.2	80.6	81.3	81.9	82.4
Scattering coefficient, m^2/kg	35.2	38.2	38.9	39.5	40.4
CIE whiteness	71.6	71.7	71.8	72.5	73.9
Yellowness	7.30	6.95	6.85	6.49	6.39
L*	95.8	95.4	95.5	95.6	95.7
a*	-0.24	-0.06	-0.07	-0.07	-0.09
b*	3.98	3.68	3.54	3.48	3.41

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 5 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Blank: beaten MHW pulp to 30^0 SR without addition of wet-end chemicals*

Table 39: Properties of MHW pulp with talc and cationic strength additive at 10 kg/t

Talc addition, %	Reference*	28	34	40	47
Retained ash, %	16.4	17.0	19.7	22.8	24.9
FPAR, %	74.5	77.7	77.8	79.8	78.0
CSF, ml	485	485	500	505	510
Streaming potential, mV	-265	-240	-260	-265	-275
Charge demand, µeq/l	5.6	5.4	5.6	5.8	6.0
Zeta potential, mV	-13.7	-12.4	-12.8	-13.7	-14.3
Conductivity, mS	0.429	0.428	0.434	0.431	0.437
Bulk, cc/g	1.32	1.34	1.33	1.33	1.30
Breaking length, m	4694	4743	4374	3877	3669
Burst index, kN/g	2.68	2.79	2.65	2.32	2.20
Tear index, mNm^2/g	5.73	5.89	5.52	5.24	5.10
Double fold, no.	16	18	16	12	10
ZD tensile strength, kPa	797	801	768	746	706
Bending stiffness, mNm	0.179	0.203	0.185	0.183	0.194
Air permeance, Gurley s	15.8	12.3	12.0	11.5	10.8
Bendtsen roughness, ml/min	140	140	140	137	126
Brightness, %ISO	84.3	84.4	84.7	85.1	85.4
Opacity, %ISO	80.6	81.5	81.7	82.4	83.2
Scattering coefficient, m^2/kg	38.2	38.6	40.4	41.7	42.0
CIE whiteness	71.7	71.9	72.3	72.8	73.6
Yellowness	6.95	6.88	6.81	6.60	6.33
L*	95.4	95.5	95.6	95.7	95.7
a*	-0.06	-0.08	-0.07	-0.08	-0.09
b*	3.68	3.70	3.61	3.45	3.42

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 10 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHW with talc and CS, 5 kg/t at 15% ash level*

Table 40: Properties of MHW pulp with talc and cationic strength additive at 15 kg/t

Talc addition, %	Reference*	28	34	40	47
Retained ash, %	16.4	17.4	20.2	23.0	25.8
FPAR, %	74.5	79.5	79.6	80.5	80.8
CSF, ml	485	515	520	525	530
Streaming potential, mV	-265	-200	-220	-235	-230
Charge demand, µeq/l	5.6	5.2	5.5	5.9	5.9
Zeta potential, mV	-13.7	-9.4	-10.4	-11.8	-12.2
Conductivity, mS	0.429	0.429	0.434	0.433	0.438
Bulk, cc/g	1.32	1.33	1.32	1.30	1.29
Breaking length, m	4694	4885	4429	4103	3903
Burst index, kN/g	2.68	2.94	2.78	2.59	2.52
Tear index, mNm^2/g	5.73	6.01	5.46	5.35	5.21
Double fold, no.	16	21	18	14	12
ZD tensile strength, kPa	797	841	815	790	760
Bending stiffness, mNm	0.179	0.203	0.185	0.183	0.194
Air permeance, Gurley s	15.8	12.3	12.0	11.5	10.8
Bendtsen roughness, ml/min	140	140	140	137	126
Brightness, %ISO	84.3	84.4	84.7	85.1	85.4
Opacity, %ISO	80.6	81.7	82.3	82.8	83.6
Scattering coefficient, m^2/kg	38.2	38.9	39.2	42.5	43.1
CIE whiteness	71.7	72.2	72.7	73.2	73.9
Yellowness	6.95	6.80	6.61	6.50	6.31
L*	95.4	95.5	95.7	95.8	96.0
a*	-0.06	-0.10	-0.11	-0.09	-0.12
b*	3.68	3.68	3.54	3.48	3.41

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 15 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHW with talc and CS, 5 kg/t at 15% ash level*

Table 41: Properties of MHW pulp with talc and amphoteric strength additive at 5 kg/t

Talc addition, %	Reference*	28	34	40	47
Retained ash, %	16.4	16.9	19.8	22.9	25.4
FPAR, %	74.5	77.3	78.0	80.2	79.3
CSF, ml	485	475	475	485	495
Streaming potential, mV	-265	-235	-261	-255	-272
Charge demand, µeq/l	5.6	3.7	4.2	4.5	5.2
Zeta potential, mV	-13.7	-11.0	-10.6	-11.8	-12.6
Conductivity, mS	0.429	0.414	0.411	0.423	0.425
Bulk, cc/g	1.32	1.32	1.32	1.30	1.28
Breaking length, m	4694	4715	4511	4265	3673
Burst index, kN/g	2.68	3.05	2.85	2.46	2.12
Tear index, mNm^2/g	5.73	5.69	5.10	4.91	4.89
Double fold, no.	16	14	12	11	10
ZD tensile strength, kPa	797	780	769	745	729
Bending stiffness, mNm	0.179	0.185	0.164	0.160	0.152
Air permeance, Gurley s	15.8	14.2	13.3	12.2	11.3
Bendtsen roughness, ml/min	140	147	135	131	126
Brightness, %ISO	84.3	83.8	84.2	84.6	84.8
Opacity, %ISO	80.6	80.7	81.4	81.6	82.0
Scattering coefficient, m^2/kg	38.2	38.6	39.4	40.4	40.8
CIE whiteness	71.7	70.6	71.9	72.9	72.9
Yellowness	6.95	6.84	6.69	6.57	6.46
L*	95.4	95.3	95.4	95.5	95.6
a*	-0.06	-0.05	-0.15	-0.09	-0.07
b*	3.68	3.84	3.64	3.51	3.55

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 5 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHW with talc and CS, 5 kg/t at 15% ash level*

Table 42: Properties of MHW pulp with talc and amphoteric strength additive at 10 kg/t

Talc addition, %	Reference*	28	34	40	47
Retained ash, %	16.4	17.4	20.5	23.0	25.8
FPAR, %	74.5	80.0	80.8	80.5	80.7
CSF, ml	485	480	485	490	505
Streaming potential, mV	-265	-215	-228	-235	-246
Charge demand, µeq/l	5.6	3.7	3.8	4.2	4.7
Zeta potential, mV	-13.7	-6.1	-7.0	-7.2	-7.6
Conductivity, mS	0.429	0.425	0.428	0.428	0.432
Bulk, cc/g	1.32	1.32	1.31	1.30	1.29
Breaking length, m	4694	4811	4621	4324	3855
Burst index, kN/g	2.68	3.10	2.90	2.72	2.46
Tear index, mNm^2/g	5.73	5.72	5.46	5.35	5.15
Double fold, no.	16	18	16	14	12
ZD tensile strength, kPa	797	755	739	730	721
Bending stiffness, mNm	0.179	0.193	0.176	0.163	0.158
Air permeance, Gurley s	15.8	13.1	12.9	10.5	13.0
Bendtsen roughness, ml/min	140	146	130	130	121
Brightness, %ISO	84.3	83.9	84.3	84.8	85.2
Opacity, %ISO	80.6	81.3	81.7	82.1	82.6
Scattering coefficient, m^2/kg	38.2	39.6	40.5	40.9	41.3
CIE whiteness	71.7	71.9	72.5	73.1	73.4
Yellowness	6.95	6.81	6.68	6.48	6.43
L*	95.4	95.4	95.4	95.5	95.6
a*	-0.06	-0.1	-0.07	-0.1	-0.09
b*	3.68	3.86	3.56	3.47	3.44

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 10 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHW with talc and CS, 5 kg/t at 15% ash level*

Table 43: Properties of MHW pulp with talc and amphoteric strength additive at 15 kg/t

Talc addition, %	Reference*	28	34	40	47
Retained ash, %	16.4	17.7	20.8	23.5	26.2
FPAR, %	74.5	80.9	82.0	82.2	82.0
CSF, ml	485	480	490	510	520
Streaming potential, mV	-265	-187	-203	-219	-218
Charge demand, µeq/l	5.6	3.6	4.3	4.8	5.1
Zeta potential, mV	-13.7	-2.0	-2.2	-2.5	-3.1
Conductivity, mS	0.429	0.426	0.421	0.423	0.436
Bulk, cc/g	1.32	1.33	1.32	1.30	1.29
Breaking length, m	4694	4971	4742	4567	4166
Burst index, kN/g	2.68	3.28	3.08	2.90	2.56
Tear index, mNm^2/g	5.73	5.76	5.68	5.35	5.17
Double fold, no.	16	26	23	15	14
ZD tensile strength, kPa	797	742	732	721	712
Bending stiffness, mNm	0.179	0.198	0.182	0.175	0.178
Air permeance, Gurley s	15.8	13.0	12.7	11.6	11.8
Bendtsen roughness, ml/min	140	127	131	123	118
Brightness, %ISO	84.3	84.9	84.5	84.8	85.5
Opacity, %ISO	80.6	81.8	82.0	82.7	83.1
Scattering coefficient, m^2/kg	38.2	39.2	40.8	41.6	42.3
CIE whiteness	71.7	71.4	72.9	73.7	74.7
Yellowness	6.95	6.73	6.29	6.17	5.98
L*	95.4	95.5	95.5	95.4	95.6
a*	-0.06	-0.12	-0.14	-0.11	-0.11
b*	3.68	3.61	3.38	3.31	3.20

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 15 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHW with talc and CS, 5 kg/t at 15% ash level*

Table 44: Properties of MHW pulp with talc and polymeric strength additive at 6 kg/t

Talc addition, %	Reference*	28	34	40	47
Retained ash, %	16.4	17.4	20.6	23.1	25.8
FPAR, %	74.5	79.7	81.4	80.9	80.8
CSF, ml	485	410	420	450	455
Streaming potential, mV	-265	-234	-252	-276	-287
Charge demand, µeq/l	5.6	7.5	5.7	7.6	8.6
Zeta potential, mV	-13.7	-11.8	-11.7	-11.8	-11.1
Conductivity, mS	0.429	0.412	0.408	0.418	0.420
Bulk, cc/g	1.32	1.32	1.31	1.30	1.30
Breaking length, m	4694	4627	4304	4070	3780
Burst index, kN/g	2.68	2.66	2.47	2.30	2.17
Tear index, mNm^2/g	5.73	5.30	5.12	4.87	4.71
Double fold, no.	16	12	10	9	8
ZD tensile strength, kPa	797	784	760	740	726
Bending stiffness, mNm	0.179	0.178	0.174	0.169	0.158
Air permeance, Gurley s	15.8	19.0	20.3	15.6	14.0
Bendtsen roughness, ml/min	140	124	119	116	111
Brightness, %ISO	84.3	84.5	85.0	85.2	85.5
Opacity, %ISO	80.6	80.9	81.3	81.8	82.1
Scattering coefficient, m^2/kg	38.2	38.5	38.9	39.1	40.5
CIE whiteness	71.7	73.1	73.4	73.6	74.2
Yellowness	6.95	6.48	6.31	6.04	5.91
L*	95.4	95.4	95.7	95.7	95.8
a*	-0.06	-0.11	-0.12	-0.11	-0.14
b*	3.68	3.31	3.27	3.25	3.15

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + PS, 6 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHW with talc and CS, 5 kg/t at 15% ash level*

Table 45: Properties of MHW pulp with talc and polymeric strength additive at 8 kg/t

Talc addition, %	Reference*	28	34	40	47
Retained ash, %	16.4	17.7	21.4	23.3	26.2
FPAR, %	74.5	81.0	82.5	81.6	81.9
CSF, ml	485	420	430	455	465
Streaming potential, mV	-265	-230	-258	-280	-282
Charge demand, µeq./l	5.6	7.4	8.1	8.6	9.3
Zeta potential, mV	-13.7	-12.0	-12.9	-13.2	-13.6
Conductivity, mS	0.429	0.420	0.428	0.429	0.431
Bulk, cc/g	1.32	1.33	1.31	1.31	1.29
Breaking length, m	4694	4659	4455	4281	3959
Burst index, kN/g	2.68	2.80	2.55	2.45	2.27
Tear index, mNm^2/g	5.73	5.40	5.23	5.01	4.86
Double fold, no.	16	15	13	11	9
ZD tensile strength, kPa	797	782	771	757	687
Bending stiffness, mNm	0.179	0.186	0.163	0.169	0.157
Air permeance, Gurley s	15.8	16.5	17.3	15.0	13.0
Bendtsen roughness, ml/min	140	126	116	110	108
Brightness, %ISO	84.3	84.4	84.8	85.0	85.3
Opacity, %ISO	80.6	81.1	81.5	82.4	82.8
Scattering coefficient, m^2/kg	38.2	39.6	39.9	40.4	40.8
CIE whiteness	71.7	73.0	73.2	73.4	74.1
Yellowness	6.95	6.43	6.25	6.04	5.88
L*	95.4	95.6	95.6	95.7	95.9
a*	-0.06	-0.1	-0.15	-0.1	-0.12
b*	3.68	3.43	3.28	3.24	3.19

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + PS, 8 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHW with talc and CS, 5 kg/t at 15% ash level*

Table 46: Properties of MHW pulp with talc and polymeric strength additive at 10 kg/t

Talc addition, %	Reference*	28	34	40	47
Retained ash, %	16.4	17.9	21.1	23.4	26.4
FPAR, %	74.5	81.8	83.3	82.1	82.6
CSF, ml	485	440	450	460	475
Streaming potential, mV	-265	-240	-265	-270	-288
Charge demand, µeq/l	5.6	7.5	8.5	9.1	10.5
Zeta potential, mV	-13.7	-13.2	-13.9	-12.8	-14.3
Conductivity, mS	0.429	0.421	0.422	0.432	0.436
Bulk, cc/g	1.32	1.32	1.30	1.29	1.28
Breaking length, m	4694	4875	4668	4496	4158
Burst index, kN/g	2.68	2.87	2.59	2.49	2.35
Tear index, mNm^2/g	5.73	5.61	5.42	5.25	5.05
Double fold, no.	16	19	14	11	10
ZD tensile strength, kPa	797	786	763	760	695
Bending stiffness, mNm	0.179	0.179	0.179	0.177	0.167
Air permeance, Gurley s	15.8	14.0	13.2	14.7	15.3
Bendtsen roughness, ml/min	140	122	119	116	109
Brightness, %ISO	84.3	84.2	84.6	84.8	85.0
Opacity, %ISO	80.6	81.6	81.9	82.7	83.5
Scattering coefficient, m^2/kg	38.2	39.8	40.3	41.6	42.5
CIE whiteness	71.7	72.5	73.1	73.3	73.9
Yellowness	6.95	6.13	6.17	6.03	5.84
L*	95.4	95.6	95.6	95.7	95.7
a*	-0.06	-0.08	-0.11	-0.09	-0.11
b*	3.68	3.46	3.34	3.27	3.18

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + PS, 10 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHW with talc and CS, 5 kg/t at 15% ash level*

Table 47: Properties of MHW pulp with GCC and cationic strength additive at 5 kg/t

GCC addition, %	Blank*	40	48	56	67
Retained ash, %	0.6	16.7	19.5	21.3	23.2
FPAR, %	-	58.6	60.1	59.4	57.8
CSF, ml	430	445	455	470	480
Streaming potential, mV	-240	-200	-152	-140	-138
Charge demand, µeq/l	10.0	10.2	8.2	6.7	5.2
Zeta potential, mV	-24.4	-15.2	-14.4	-14.3	-14.3
Conductivity, mS	0.433	0.341	0.346	0.346	0.360
Bulk, cc/g	1.36	1.34	1.33	1.30	1.28
Breaking length, m	5251	3831	3355	3132	2933
Burst index, kN/g	3.68	2.15	2.07	1.82	1.75
Tear index, mNm^2/g	7.11	5.63	5.25	5.03	4.54
Double fold, no.	27	8	7	6	6
ZD tensile strength, kPa	788	720	712	688	666
Bending stiffness, mNm	0.238	0.154	0.141	0.137	0.132
Air permeance, Gurley s	15.4	16.7	16.5	16.1	12.3
Bendtsen roughness, ml/min	122	91	102	102	99
Brightness, %ISO	84.6	87.3	87.5	87.6	88.4
Opacity, %ISO	77.2	84.5	85.7	86.3	86.7
Scattering coefficient, m^2/kg	35.2	49.0	53.5	55.5	58.9
CIE whiteness	71.6	78.3	79.7	79.6	80.2
Yellowness	7.30	4.83	4.52	4.51	4.17
L*	95.8	96.1	96.3	96.3	96.5
a*	-0.24	-0.14	-0.15	-0.24	-0.20
b*	3.98	2.65	2.45	2.49	2.29

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 5 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Blank: beaten MHW pulp to 30^0 SR without addition of wet-end chemical*

Table 48: Properties of MHW pulp with GCC and cationic strength additive at 10 kg/t

GCC addition, %	Reference*	40	48	56	67
Retained ash, %	16.7	17.5	19.8	21.5	23.8
FPAR, %	58.6	61.3	61.1	59.7	59.2
CSF, ml	445	455	465	470	485
Streaming potential, mV	-200	-170	-155	-142	-120
Charge demand, µeq/l	10.2	8.1	6.2	5.4	4.8
Zeta potential, mV	-15.2	-14.3	-13.2	-12.8	-10.8
Conductivity, mS	0.341	0.347	0.352	0.356	0.370
Bulk, cc/g	1.34	1.35	1.34	1.31	1.29
Breaking length, m	3831	4057	3787	3520	3271
Burst index, kN/g	2.15	2.61	2.34	2.25	1.91
Tear index, mNm^2/g	5.63	5.83	5.36	5.16	4.90
Double fold, no.	8	11	10	10	6
ZD tensile strength, kPa	720	757	728	713	672
Bending stiffness, mNm	0.154	0.163	0.151	0.141	0.132
Air permeance, Gurley s	16.7	15.3	15.0	13.8	13.6
Bendtsen roughness, ml/min	91	105	127	99	123
Brightness, %ISO	87.3	87.2	87.4	87.5	88.0
Opacity, %ISO	84.5	84.0	85.4	85.9	86.4
Scattering coefficient, m^2/kg	49.0	48.7	52.9	54.5	58.0
CIE whiteness	78.3	77.5	77.3	78.8	79.9
Yellowness	4.83	5.49	5.35	5.14	4.84
L*	96.1	96.2	96.2	96.2	96.5
a*	-0.14	-0.16	-0.16	-0.17	-0.19
b*	2.65	2.98	2.86	2.79	2.63

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 10 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHW with GCC and CS, 5 kg/t at 16.7% ash level*

Table 49: Properties of MHW pulp with GCC and cationic strength additive at 15 kg/t

GCC addition, %	Reference*	40	48	56	67
Retained ash, %	16.7	17.8	20.2	21.9	24.3
FPAR, %	58.6	62.5	62.1	60.9	60.4
CSF, ml	445	455	470	475	485
Streaming potential, mV	-200	-143	-125	-118	-105
Charge demand, µeq/l	10.2	6.8	5.1	5.0	4.2
Zeta potential, mV	-15.2	-7.6	-9.1	-5.5	-8.4
Conductivity, mS	0.341	0.352	0.355	0.376	0.392
Bulk, cc/g	1.34	1.35	1.34	1.31	1.29
Breaking length, m	3582	4487	4073	3806	3300
Burst index, kN/g	2.16	2.72	2.42	2.30	2.03
Tear index, mNm^2/g	5.63	5.94	5.62	5.35	5.26
Double fold, no.	8	18	11	10	8
ZD tensile strength, kPa	720	761	751	721	711
Bending stiffness, mNm	0.154	0.172	0.167	0.153	0.140
Air permeance, Gurley s	16.7	15.4	11.2	11.5	11.1
Bendtsen roughness, ml/min	91	95	96	104	97
Brightness, %ISO	87.3	86.8	87.0	87.3	87.9
Opacity, %ISO	84.5	84.5	85.2	85.5	85.9
Scattering coefficient, m^2/kg	49.0	47.5	50.5	54.2	56.2
CIE whiteness	78.3	76.3	77.4	78.0	79.3
Yellowness	4.83	5.63	5.40	5.20	4.91
L*	96.1	96.0	96.3	96.4	96.5
a*	-0.14	-0.19	-0.20	-0.15	-0.17
b*	2.65	3.07	2.95	2.72	2.68

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 15 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHW with GCC and CS, 5 kg/t at 16.7% ash level*

Table 50: Properties of MHW pulp with GCC and amphoteric strength additive at 5 kg/t

GCC addition, %	Reference*	40	48	56	67
Retained ash, %	16.7	16.9	19.8	21.5	24.1
FPAR, %	58.6	59.0	60.9	59.8	60.1
CSF, ml	445	450	465	485	505
Streaming potential, mV	-200	-170	-158	-100	-106
Charge demand, µeq/l	10.2	6.1	5.5	4.8	3.2
Zeta potential, mV	-15.2	-14.4	-14.1	-13.5	-12.4
Conductivity, mS	0.341	0.345	0.341	0.342	0.346
Bulk, cc/g	1.34	1.34	1.33	1.30	1.29
Breaking length, m	3831	3757	3281	2989	2771
Burst index, kN/g	2.15	2.16	1.84	1.71	1.69
Tear index, mNm^2/g	5.63	5.72	4.86	4.75	4.36
Double fold, no.	8	9	6	5	5
ZD tensile strength, kPa	720	708	667	660	634
Bending stiffness, mNm	0.154	0.161	0.156	0.157	0.149
Air permeance, Gurley s	16.7	15.5	14.2	14.6	12.5
Bendtsen roughness, ml/min	91	86	85	85	82
Brightness, %ISO	87.3	87.4	87.6	88.0	88.4
Opacity, %ISO	84.5	84.9	85.9	87.0	88.0
Scattering coefficient, m^2/kg	49.0	50.4	53.1	56.6	60.0
CIE whiteness	78.3	78.6	78.9	80.3	80.6
Yellowness	4.83	5.23	4.92	4.49	4.56
L*	96.1	96.4	96.4	96.5	96.7
a*	-0.14	-0.13	-0.15	-0.17	-0.19
b*	2.65	2.72	2.68	2.44	2.49

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 5 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHW with GCC and CS, 5 kg/t at 16.7% ash level*

Table 51: Properties of MHW pulp with GCC and amphoteric strength additive at 10 kg/t

GCC addition, %	Reference*	40	48	56	67
Retained ash, %	16.7	17.7	19.9	21.8	24.8
FPAR, %	58.6	61.8	61.4	60.8	61.8
CSF, ml	445	470	475	485	510
Streaming potential, mV	-200	-160	-135	-80	-78
Charge demand, µeq/l	10.2	5.3	4.5	4.4	2.8
Zeta potential, mV	-15.2	-13.2	-12.8	-10.8	-9.5
Conductivity, mS	0.341	0.348	0.349	0.348	0.349
Bulk, cc/g	1.34	1.34	1.33	1.30	1.29
Breaking length, m	3831	3980	3503	3163	2951
Burst index, kN/g	2.15	2.42	2.26	2.04	1.73
Tear index, mNm^2/g	5.63	5.98	5.37	5.07	4.93
Double fold, no.	8	10	8	8	7
ZD tensile strength, kPa	720	738	717	696	688
Bending stiffness, mNm	0.154	0.172	0.161	0.147	0.138
Air permeance, Gurley s	16.7	15.9	15.0	13.2	12.8
Bendtsen roughness, ml/min	91	88	93	91	95
Brightness, %ISO	87.3	87.5	87.6	87.8	87.9
Opacity, %ISO	84.5	85.5	86.5	87.4	88.1
Scattering coefficient, m^2/kg	49.0	51.0	52.9	55.9	59.5
CIE whiteness	78.3	78.3	78.4	79.0	79.4
Yellowness	4.83	5.30	4.95	4.90	4.87
L*	96.1	96.3	96.3	96.5	96.6
a*	-0.14	-0.18	-0.15	-0.20	-0.19
b*	2.65	2.78	2.71	2.68	2.57

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 10 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHW with GCC and CS, 5 kg/t at 16.7% ash level*

Table 52: Properties of MHW pulp with GCC and amphoteric strength additive at 15 kg/t

GCC addition, %	Reference*	40	48	56	67
Retained ash, %	16.7	17.9	20.2	22.2	25.3
FPAR, %	58.6	62.4	62.1	61.8	63.1
CSF, ml	445	475	490	505	520
Streaming potential, mV	-200	-106	-98	-60	-50
Charge demand, µeq/l	10.2	4.4	3.4	2.8	2.5
Zeta potential, mV	-15.2	-10.2	-8.6	-7.2	-7.0
Conductivity, mS	0.341	0.356	0.354	0.361	0.356
Bulk, cc/g	1.34	1.32	1.31	1.31	1.28
Breaking length, m	3831	4289	3813	3587	3107
Burst index, kN/g	2.15	2.54	2.36	2.11	1.78
Tear index, mNm^2/g	5.63	6.01	5.72	5.49	5.33
Double fold, no.	8	17	12	11	7
ZD tensile strength, kPa	720	751	724	719	693
Bending stiffness, mNm	0.154	0.177	0.161	0.149	0.146
Air permeance, Gurley s	16.7	16.5	15.0	13.8	12.6
Bendtsen roughness, ml/min	91	113	97	108	79
Brightness, %ISO	87.3	87.5	87.6	87.8	87.9
Opacity, %ISO	84.5	85.7	86.3	87.4	87.9
Scattering coefficient, m^2/kg	49.0	51.4	53.3	56.6	59.7
CIE whiteness	78.3	77.5	77.9	78.4	79.1
Yellowness	4.83	5.35	5.24	5.01	4.90
L*	96.1	96.2	96.3	96.3	96.4
a*	-0.14	-0.17	-0.22	-0.20	-0.22
b*	2.65	2.89	2.87	2.74	2.64

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 15 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: MHW with GCC and CS, 5 kg/t at 16.7% ash level*

Table 53: Properties of MHW pulp with PCC and cationic strength additive at 5 kg/t

PCC addition, %	Blank*	30	36	44	52
Retained ash, %	0.6	15.3	17.6	21.1	23.2
FPAR, %	-	66.5	66.5	69.0	70.6
CSF, ml	430	490	500	515	525
Streaming potential, mV	-240	-278	-212	-198	-183
Charge demand, µeq/l	10.0	8.1	6.9	6.7	5.7
Zeta potential, mV	-24.4	-18.2	-17.2	-16.4	-15.0
Conductivity, mS	0.433	0.383	0.382	0.385	0.396
Bulk, cc/g	1.36	1.46	1.49	1.51	1.52
Breaking length, m	5251	3555	3316	3135	2866
Burst index, kN/g	3.68	1.99	1.83	1.73	1.57
Tear index, mNm^2/g	7.11	5.58	4.89	4.52	4.33
Double fold, no.	27	8	7	5	5
ZD tensile strength, kPa	788	730	715	652	630
Bending stiffness, mNm	0.238	0.180	0.174	0.171	0.170
Air permeance, Gurley s	15.4	10.6	8.8	8.7	8.0
Bendtsen roughness, ml/min	122	136	133	130	127
Brightness, %ISO	84.6	86.5	86.9	86.9	87.1
Opacity, %ISO	77.2	84.8	85.1	85.7	86.4
Scattering coefficient, m^2/kg	35.2	52.1	55.1	58.2	60.7
CIE whiteness	71.6	76.8	77.1	77.5	78.0
Yellowness	7.30	5.56	5.43	5.37	5.29
L*	95.8	96.1	96.1	96.1	96.3
a*	-0.24	-0.13	-0.11	-0.13	-0.12
b*	3.98	3.10	3.06	2.95	2.86

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 5 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Blank: beaten MHW pulp to 30^0 SR without addition of wet-end chemicals*

Table 54: Properties of MHW pulp with PCC and cationic strength additive at 10 kg/t

PCC addition, %	Reference*	30	36	44	52
Retained ash, %	15.3	15.8	18.0	21.5	23.5
FPAR, %	66.5	68.5	68.0	70.4	68.5
CSF, ml	490	495	505	520	530
Streaming potential, mV	-278	-247	-196	-185	-160
Charge demand, µeq/l	8.1	8.0	5.9	5.7	5.3
Zeta potential, mV	-18.2	-15.0	-14.7	-13.8	-12.0
Conductivity, mS	0.383	0.382	0.385	0.395	0.398
Bulk, cc/g	1.46	1.47	1.50	1.51	1.52
Breaking length, m	3555	3653	3475	3318	3148
Burst index, kN/g	1.99	2.12	1.90	1.82	1.66
Tear index, mNm^2/g	5.58	5.67	5.20	4.81	4.70
Double fold, no.	8	11	9	7	6
ZD tensile strength, kPa	730	746	733	682	646
Bending stiffness, mNm	0.180	0.211	0.182	0.187	0.180
Air permeance, Gurley s	10.6	9.0	7.2	6.9	6.7
Bendtsen roughness, ml/min	136	130	136	127	117
Brightness, %ISO	86.5	86.6	86.9	87.4	87.5
Opacity, %ISO	84.8	85.3	85.8	86.3	87.8
Scattering coefficient, m^2/kg	52.1	53.3	55.0	58.7	60.1
CIE whiteness	76.8	76.7	76.9	77.6	78.3
Yellowness	5.56	5.49	5.39	5.31	5.14
L*	96.1	96.1	96.2	96.3	96.4
a*	-0.13	-0.14	-0.16	-0.17	-0.19
b*	3.10	3.04	2.98	2.94	2.82

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 10 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: MHW with PCC and CS, 5 kg/t at 15% ash level*

Table 55: Properties of MHW pulp with PCC and cationic strength additive at 15 kg/t

PCC addition, %	Reference*	30	36	44	52
Retained ash, %	15.3	16.2	18.2	21.8	23.9
FPAR, %	66.5	70.2	68.8	71.3	64.4
CSF, ml	490	500	510	520	535
Streaming potential, mV	-278	-217	-181	-165	-145
Charge demand, µeq/l	8.1	6.7	6.4	5.4	5.1
Zeta potential, mV	-18.2	-12.2	-12.0	-11.5	-10.8
Conductivity, mS	0.383	0.384	0.388	0.394	0.399
Bulk, cc/g	1.46	1.48	1.50	1.52	1.53
Breaking length, m	3555	4355	4048	3532	3378
Burst index, kN/g	1.99	2.56	2.27	1.98	1.89
Tear index, mNm^2/g	5.58	5.91	5.52	5.30	5.18
Double fold, no.	8	18	14	10	8
ZD tensile strength, kPa	730	770	753	742	718
Bending stiffness, mNm	0.180	0.254	0.249	0.225	0.191
Air permeance, Gurley s	10.6	6.7	6.4	5.8	5.2
Bendtsen roughness, ml/min	136	125	118	118	113
Brightness, %ISO	86.5	86.6	87.1	87.8	87.7
Opacity, %ISO	84.8	86.3	87.1	88.0	88.5
Scattering coefficient, m^2/kg	52.1	53.7	55.9	58.4	60.5
CIE whiteness	76.8	77.5	78.1	78.7	79.1
Yellowness	5.56	5.26	5.13	4.94	4.91
L*	96.1	96.2	96.3	96.4	96.4
a*	-0.13	-0.16	-0.16	-0.14	-0.20
b*	3.10	2.85	2.79	2.68	2.67

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 15 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: MHW with PCC and CS, 5 kg/t at 15% ash level*

Table 56: Properties of MHW pulp with PCC and amphoteric strength additive at 5 kg/t

PCC addition, %	Reference*	30	36	44	52
Retained ash, %	15.3	15.6	17.9	21.3	23.4
FPAR, %	66.5	67.6	67.7	69.9	68.4
CSF, ml	490	445	455	465	470
Streaming potential, mV	-278	-215	-200	-181	-168
Charge demand, µeq/l	8.1	6.6	6.4	6.1	5.8
Zeta potential, mV	-18.2	-14.6	-14.0	-13.7	-13.6
Conductivity, mS	0.383	0.385	0.399	0.405	0.403
Bulk, cc/g	1.46	1.47	1.48	1.50	1.51
Breaking length, m	3555	3974	3801	3622	3407
Burst index, kN/g	1.99	2.20	2.07	1.93	1.78
Tear index, mNm^2/g	5.58	5.70	5.19	4.77	4.43
Double fold, no.	8	11	10	7	5
ZD tensile strength, kPa	730	769	742	725	682
Bending stiffness, mNm	0.180	0.219	0.202	0.194	0.183
Air permeance, Gurley s	10.6	9.0	8.4	8.0	7.6
Bendtsen roughness, ml/min	136	127	124	124	122
Brightness, %ISO	86.5	86.7	87.6	87.7	88.2
Opacity, %ISO	84.8	85.9	86.8	87.5	88.1
Scattering coefficient, m^2/kg	52.1	54.4	56.1	59.5	61.1
CIE whiteness	76.8	77.2	77.7	78.8	79.8
Yellowness	5.56	5.42	5.20	5.04	4.90
L*	96.1	96.3	96.5	96.6	96.7
a*	-0.13	-0.10	-0.14	-0.15	-0.15
b*	3.10	2.95	2.83	2.74	2.70

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 5 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: MHW with PCC and CS, 5 kg/t at 15% ash level*

Table 57: Properties of MHW pulp with PCC and amphoteric strength additive at 10 kg/t

PCC addition, %	Reference*	30	36	44	52
Retained ash, %	15.3	15.9	18.2	21.7	23.7
FPAR, %	66.5	69.1	68.8	71.0	69.3
CSF, ml	490	445	465	470	480
Streaming potential, mV	-278	-190	-171	-161	-145
Charge demand, µeq/l	8.1	6.3	6.1	6.1	5.7
Zeta potential, mV	-18.2	-8.1	-7.1	-6.1	-5.5
Conductivity, mS	0.383	0.394	0.400	0.400	0.405
Bulk, cc/g	1.46	1.47	1.47	1.50	1.52
Breaking length, m	3555	4383	4151	3836	3627
Burst index, kN/g	1.99	2.67	2.50	2.23	2.08
Tear index, mNm^2/g	5.58	5.87	5.45	5.19	4.96
Double fold, no.	8	18	12	9	9
ZD tensile strength, kPa	730	808	775	768	733
Bending stiffness, mNm	0.180	0.233	0.200	0.197	0.189
Air permeance, Gurley s	10.6	8.7	7.8	7.7	6.7
Bendtsen roughness, ml/min	136	132	123	124	120
Brightness, %ISO	86.5	86.5	87.0	87.5	87.6
Opacity, %ISO	84.8	86.2	87.1	87.7	88.3
Scattering coefficient, m^2/kg	52.1	53.1	55.6	59.3	60.9
CIE whiteness	76.8	77.6	78.4	78.8	79.5
Yellowness	5.56	5.34	5.22	5.16	4.78
L*	96.1	96.3	96.3	96.6	96.6
a*	-0.13	-0.13	-0.15	-0.16	-0.16
b*	3.10	2.90	2.80	2.71	2.64

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 10 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: MHW with PCC and CS, 5 kg/t at 15% ash level*

Table 58: Properties of MHW pulp with PCC and amphoteric strength additive at 15 kg/t

PCC addition, %	Reference*	30	36	44	52
Retained ash, %	15.3	16.3	18.4	21.9	24.1
FPAR, %	66.5	70.8	69.7	72.0	70.4
CSF, ml	490	450	470	485	490
Streaming potential, mV	-278	-176	-156	-141	-135
Charge demand, µeq/l	8.1	5.8	5.6	5.0	4.8
Zeta potential, mV	-18.2	-3.1	-2.7	-2.3	-1.1
Conductivity, mS	0.383	0.386	0.399	0.399	0.401
Bulk, cc/g	1.46	1.48	1.50	1.51	1.52
Breaking length, m	3555	4531	4227	4079	3755
Burst index, kN/g	1.99	2.83	2.68	2.46	2.34
Tear index, mNm^2/g	5.58	6.01	5.60	5.33	5.28
Double fold, no.	8	23	16	13	10
ZD tensile strength, kPa	730	855	815	757	740
Bending stiffness, mNm	0.180	0.238	0.225	0.220	0.216
Air permeance, Gurley s	10.6	8.1	7.4	6.8	6.7
Bendtsen roughness, ml/min	136	123	121	118	110
Brightness, %ISO	86.5	86.3	87.2	87.3	87.5
Opacity, %ISO	84.8	86.5	87.4	87.9	88.6
Scattering coefficient, m^2/kg	52.1	52.7	55.6	58.9	60.3
CIE whiteness	76.8	77.0	78.0	78.3	78.7
Yellowness	5.56	5.22	5.18	5.02	4.67
L*	96.1	96.3	96.4	96.4	96.6
a*	-0.13	-0.16	-0.18	-0.18	-0.20
b*	3.10	2.85	2.76	2.66	2.60

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 15 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: MHW with PCC and CS, 5 kg/t at 15% ash level*

Table 59: Properties of MHW pulp with PCC and polymeric strength additive at 6 kg/t

PCC addition, %	Reference*	30	36	44	52
Retained ash, %	15.3	14.6	17.6	20.1	22.3
FPAR, %	66.5	63.3	66.5	65.8	66.1
CSF, ml	490	425	435	450	465
Streaming potential, mV	-278	-205	-185	-176	-178
Charge demand, µeq/l	8.1	7.2	6.9	6.7	6.5
Zeta potential, mV	-18.2	-14.1	-13.8	-12.5	-12.0
Conductivity, mS	0.383	0.380	0.385	0.392	0.402
Bulk, cc/g	1.46	1.44	1.44	1.46	1.46
Breaking length, m	3555	4049	3853	3656	3460
Burst index, kN/g	1.99	2.46	2.42	2.06	1.99
Tear index, mNm^2/g	5.58	5.65	5.44	5.05	4.91
Double fold, no.	8	9	8	6	5
ZD tensile strength, kPa	730	720	706	697	691
Bending stiffness, mNm	0.180	0.205	0.203	0.190	0.186
Air permeance, Gurley s	10.6	10.9	10.8	8.9	8.8
Bendtsen roughness, ml/min	136	124	117	110	104
Brightness, %ISO	86.5	86.9	87.5	87.7	88.0
Opacity, %ISO	84.8	84.4	85.4	86.7	87.7
Scattering coefficient, m^2/kg	52.1	52.0	54.6	57.3	59.3
CIE whiteness	76.8	77.9	78.8	78.9	79.3
Yellowness	5.56	5.25	5.11	4.85	4.73
L*	96.1	96.3	96.5	96.5	96.7
a*	-0.13	-0.16	-0.17	-0.13	-0.15
b*	3.10	2.85	2.79	2.71	2.58

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + PS, 6 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: MHW with PCC and CS, 5 kg/t at 15% ash level*

Table 60: Properties of MHW pulp with PCC and polymeric strength additive at 8 kg/t

PCC addition, %	Reference*	30	36	44	52
Retained ash, %	15.3	14.8	17.1	19.6	21.4
FPAR, %	66.5	64.0	64.8	64.0	63.3
CSF, ml	490	400	420	430	445
Streaming potential, mV	-278	-208	-195	-183	-173
Charge demand, µeq/l	8.1	7.8	7.8	7.5	7.1
Zeta potential, mV	-18.2	-14.7	-14.0	-12.8	-12.5
Conductivity, mS	0.383	0.377	0.387	0.394	0.397
Bulk, cc/g	1.46	1.43	1.44	1.47	1.48
Breaking length, m	3555	4130	4014	3747	3660
Burst index, kN/g	1.99	2.54	2.45	2.27	2.06
Tear index, mNm^2/g	5.58	5.83	5.57	5.17	5.05
Double fold, no.	8	10	7	6	6
ZD tensile strength, kPa	730	726	715	706	693
Bending stiffness, mNm	0.180	0.206	0.200	0.195	0.190
Air permeance, Gurley s	10.6	10.3	9.1	8.3	8.2
Bendtsen roughness, ml/min	136	124	120	112	102
Brightness, %ISO	86.5	86.7	87.3	87.5	87.7
Opacity, %ISO	84.8	85.0	85.5	86.7	87.9
Scattering coefficient, m^2/kg	52.1	53.0	55.0	56.9	59.6
CIE whiteness	76.8	77.6	78.7	78.7	78.8
Yellowness	5.56	4.98	4.92	4.77	4.71
L*	96.1	96.3	96.4	96.5	96.6
a*	-0.13	-0.21	-0.21	-0.20	-0.19
b*	3.10	2.78	2.70	2.67	2.64

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + PS, 8 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: MHW with PCC and CS, 5 kg/t at 15% ash level*

Table 61: Properties of MHW pulp with PCC and polymeric strength additive at 10 kg/t

PCC addition, %	Reference*	30	36	44	52
Retained ash, %	15.3	14.7	16.0	19.1	20.6
FPAR, %	66.5	63.5	60.4	62.5	61.1
CSF, ml	490	390	405	415	430
Streaming potential, mV	-278	-212	-200	-186	-180
Charge demand, µeq/l	8.1	8.4	8.2	8.0	7.3
Zeta potential, mV	-18.2	-15.8	-14.8	-13.2	-12.1
Conductivity, mS	0.383	0.388	0.379	0.379	0.389
Bulk, cc/g	1.46	1.42	1.45	1.45	1.46
Breaking length, m	3555	4336	4149	3916	3675
Burst index, kN/g	1.99	2.69	2.46	2.35	2.23
Tear index, mNm^2/g	5.58	6.00	5.72	5.33	5.12
Double fold, no.	8	11	9	7	7
ZD tensile strength, kPa	730	740	718	711	703
Bending stiffness, mNm	0.180	0.218	0.205	0.201	0.196
Air permeance, Gurley s	10.6	10.4	9.5	8.4	8.1
Bendtsen roughness, ml/min	136	126	124	115	100
Brightness, %ISO	86.5	86.5	87.1	87.4	87.2
Opacity, %ISO	84.8	85.0	85.3	86.2	87.2
Scattering coefficient, m^2/kg	52.1	52.6	55.1	56.3	60.1
CIE whiteness	76.8	77.3	78.1	78.4	78.6
Yellowness	5.56	4.89	4.61	4.73	4.67
L*	96.1	96.3	96.3	96.6	96.7
a*	-0.13	-0.23	-0.20	-0.18	-0.17
b*	3.10	2.69	2.59	2.59	2.56

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + PS, 10 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: MHW with PCC and CS, 5 kg/t at 15% ash level*

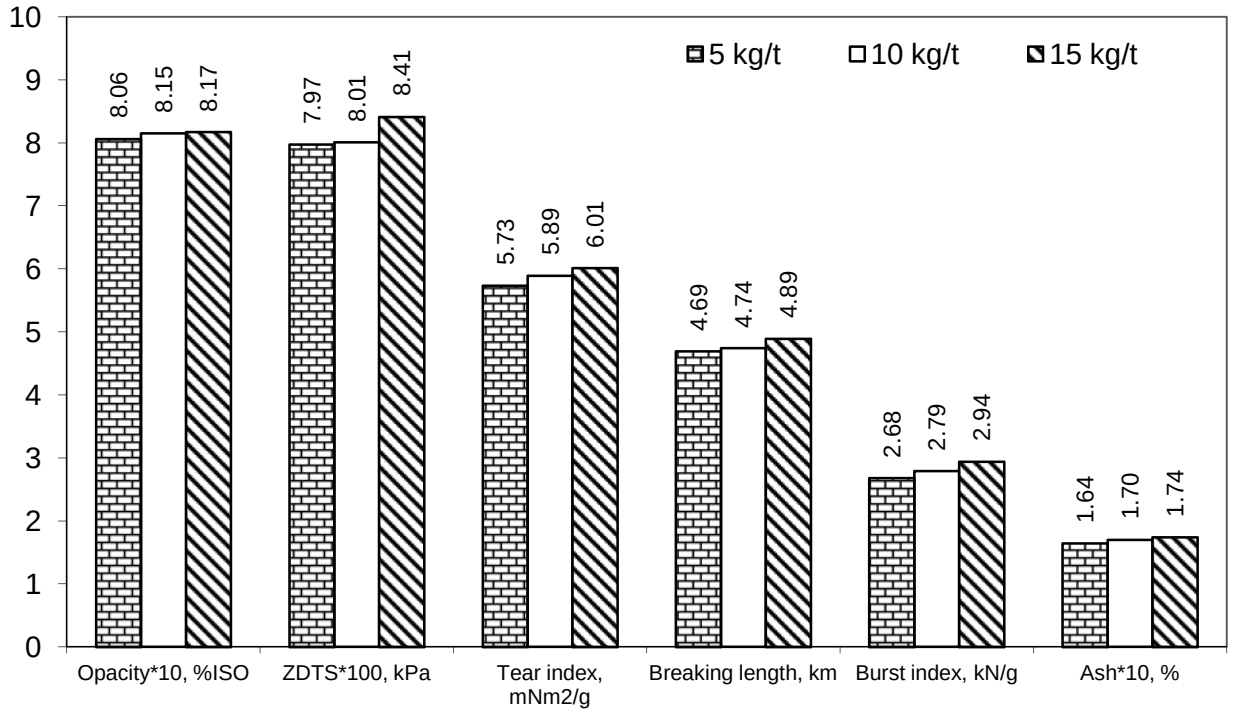

Figure 37: Effect of CS on properties of MHW pulp at 280 kg/t addition of talc

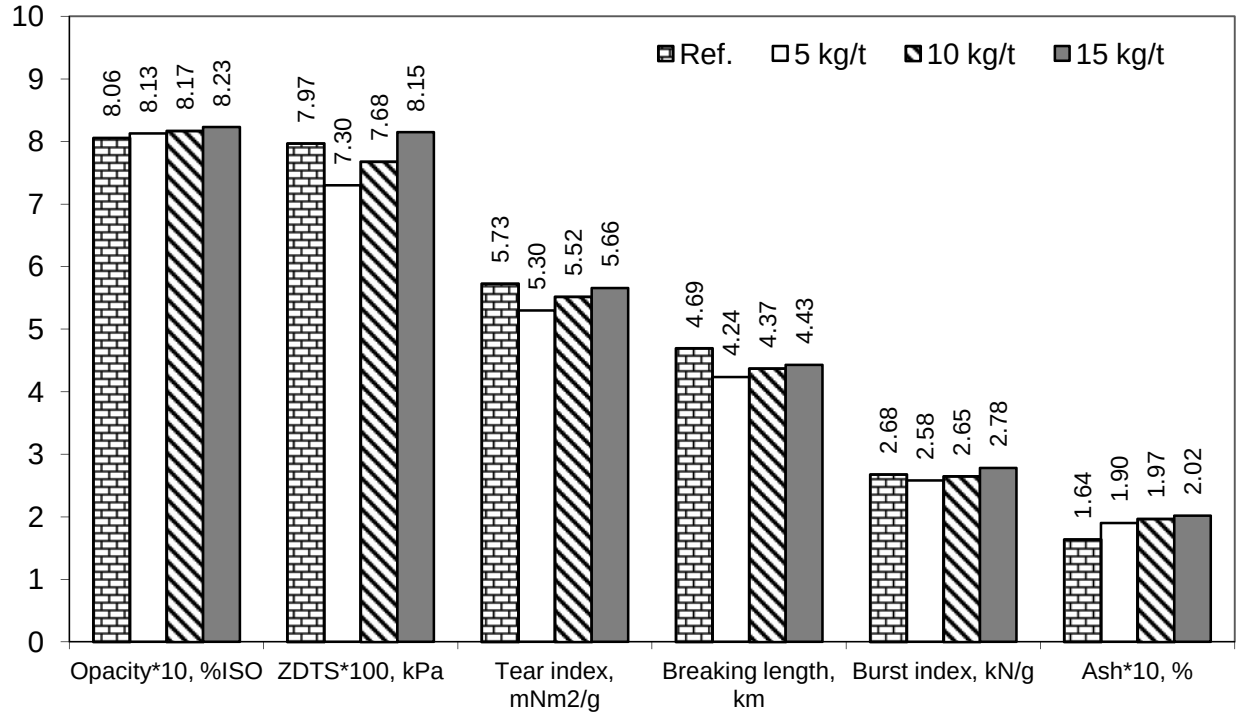

Figure 38: Effect of CS on properties of MHW pulp at 340 kg/t addition of talc

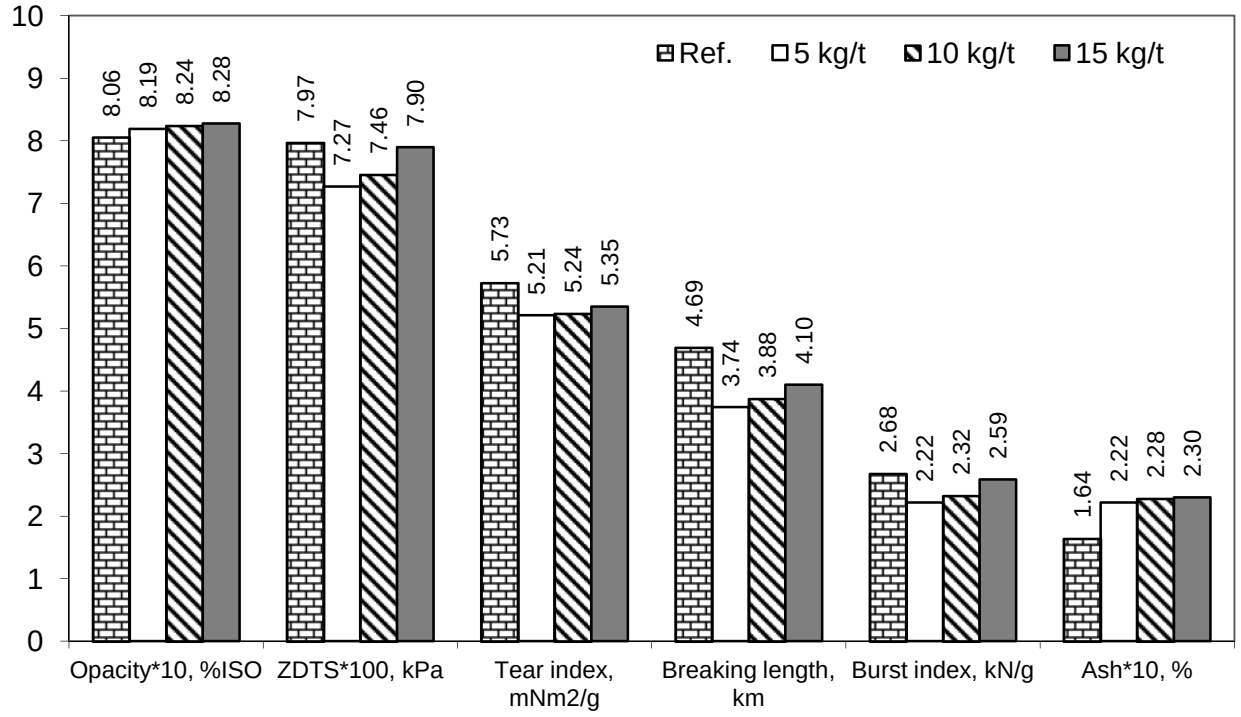

Figure 39: Effect of CS on properties of MHW pulp at 400 kg/t addition of talc

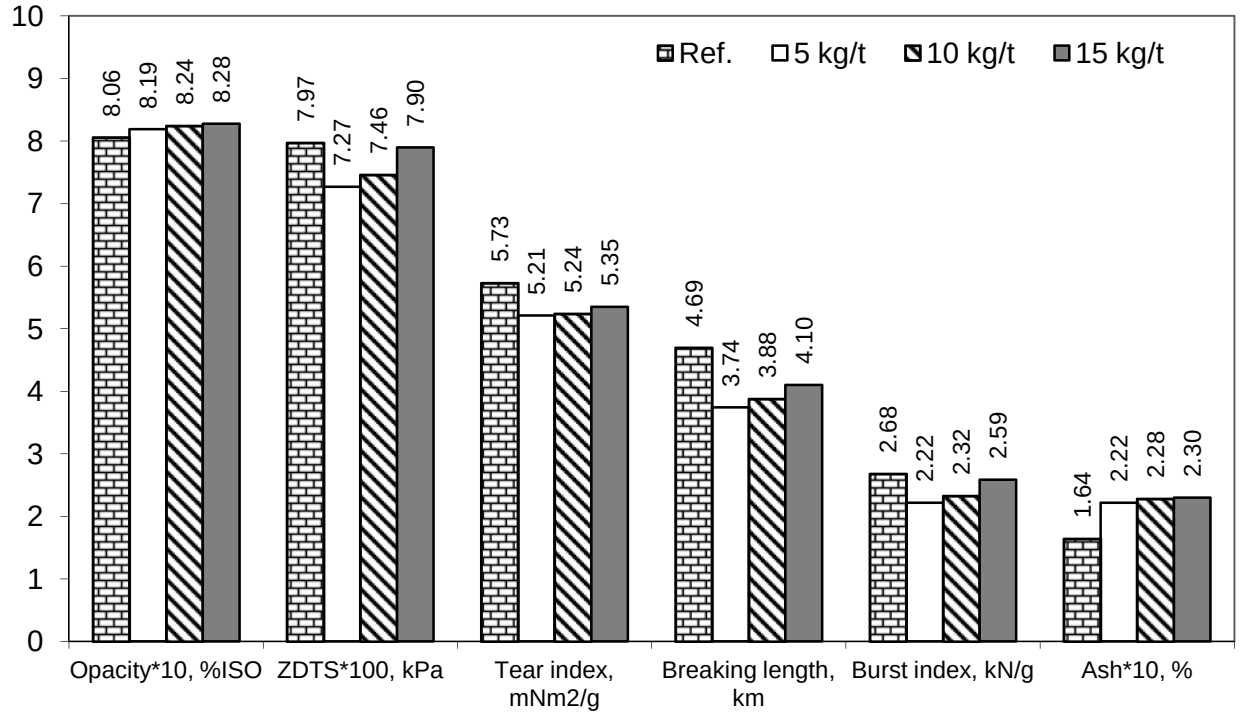

Figure 40: Effect of CS on properties of MHW pulp at 470 kg/t addition of talc

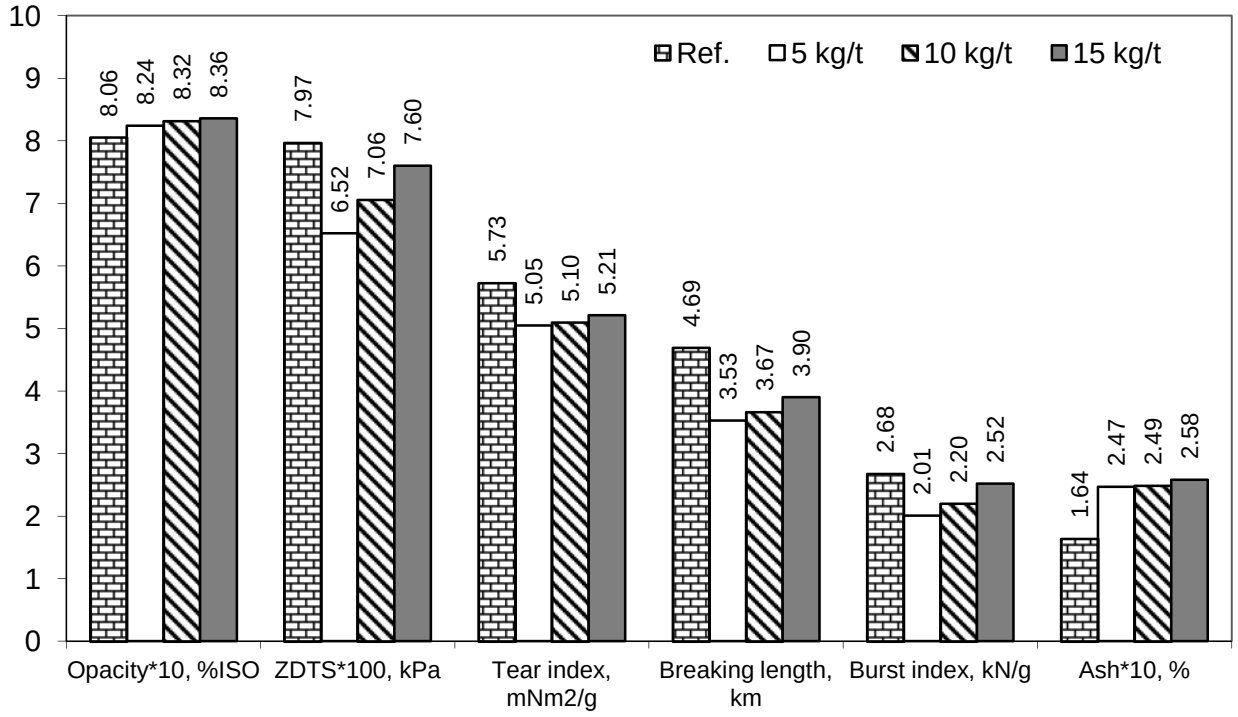

Figure 41: Effect of AS on properties of MHW pulp at 280 kg/t addition of talc

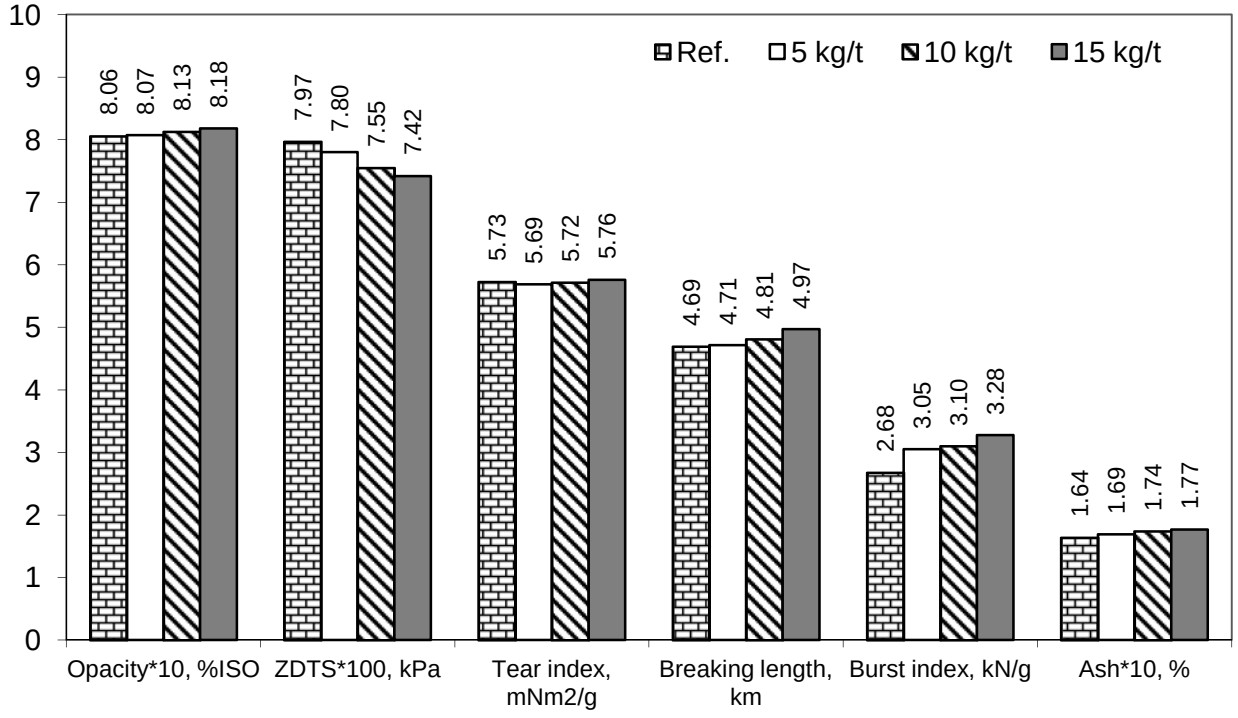

Figure 42: Effect of AS on properties of MHW pulp at 340 kg/t addition of talc

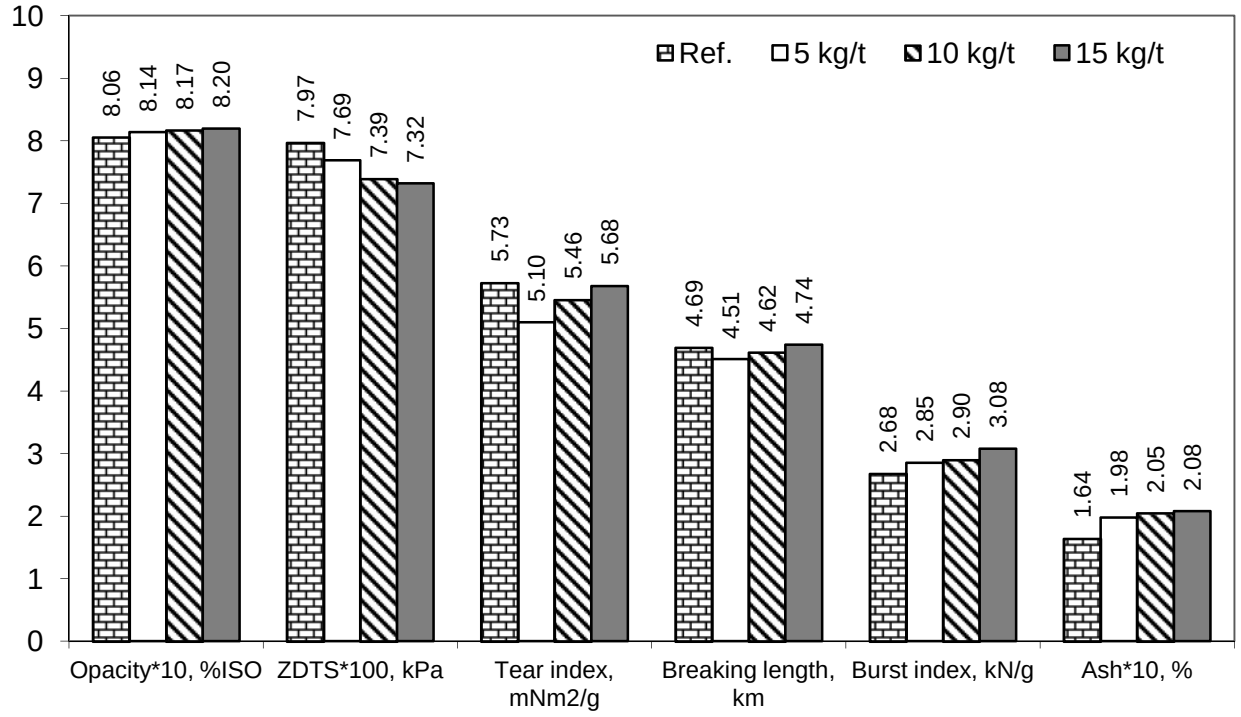

Figure 43: Effect of AS on properties of MHW pulp at 400 kg/t addition of talc

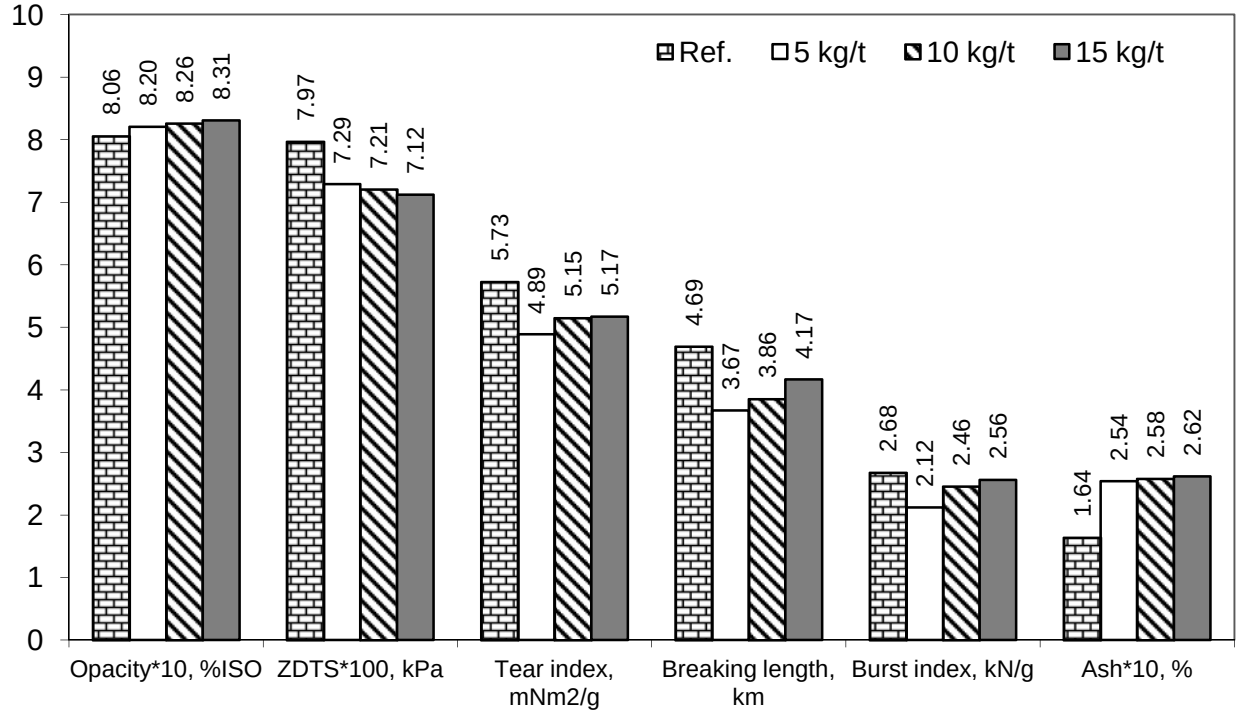

Figure 44: Effect of AS on properties of MHW pulp at 470 kg/t addition of talc

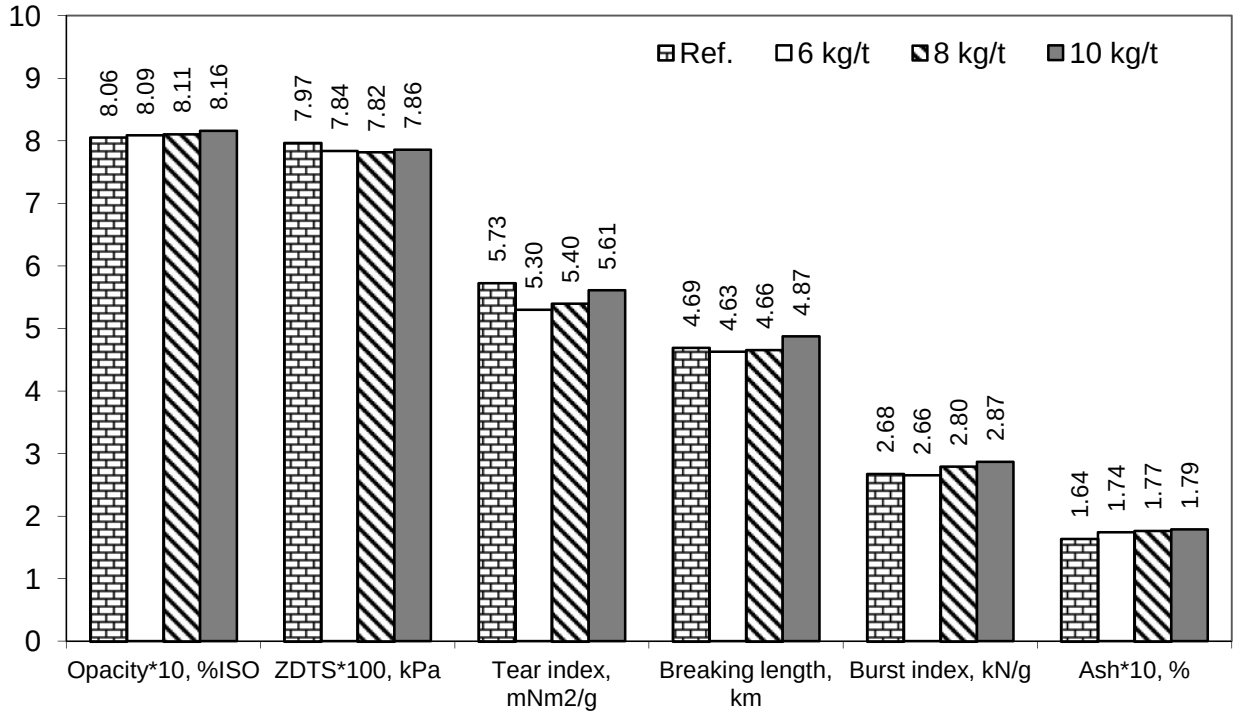

Figure 45: Effect of PS on properties of MHW pulp at 280 kg/t addition of talc

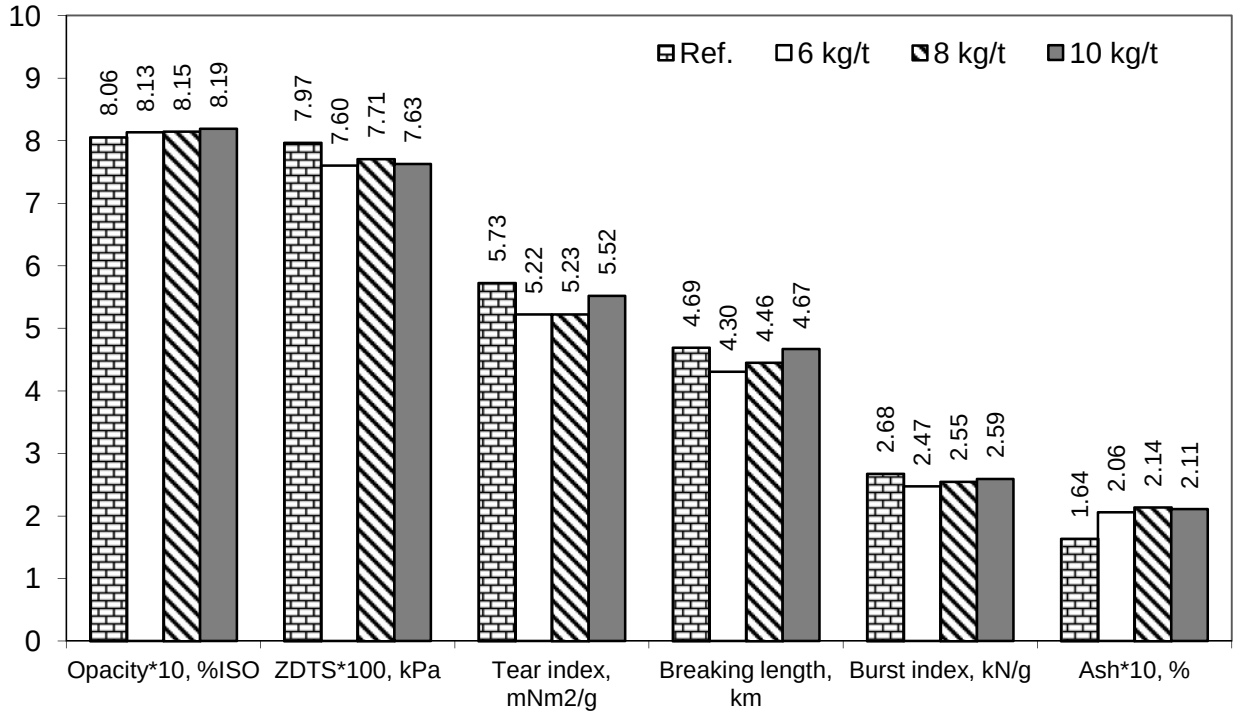

Figure 46: Effect of PS on properties of MHW pulp at 340 kg/t addition of talc

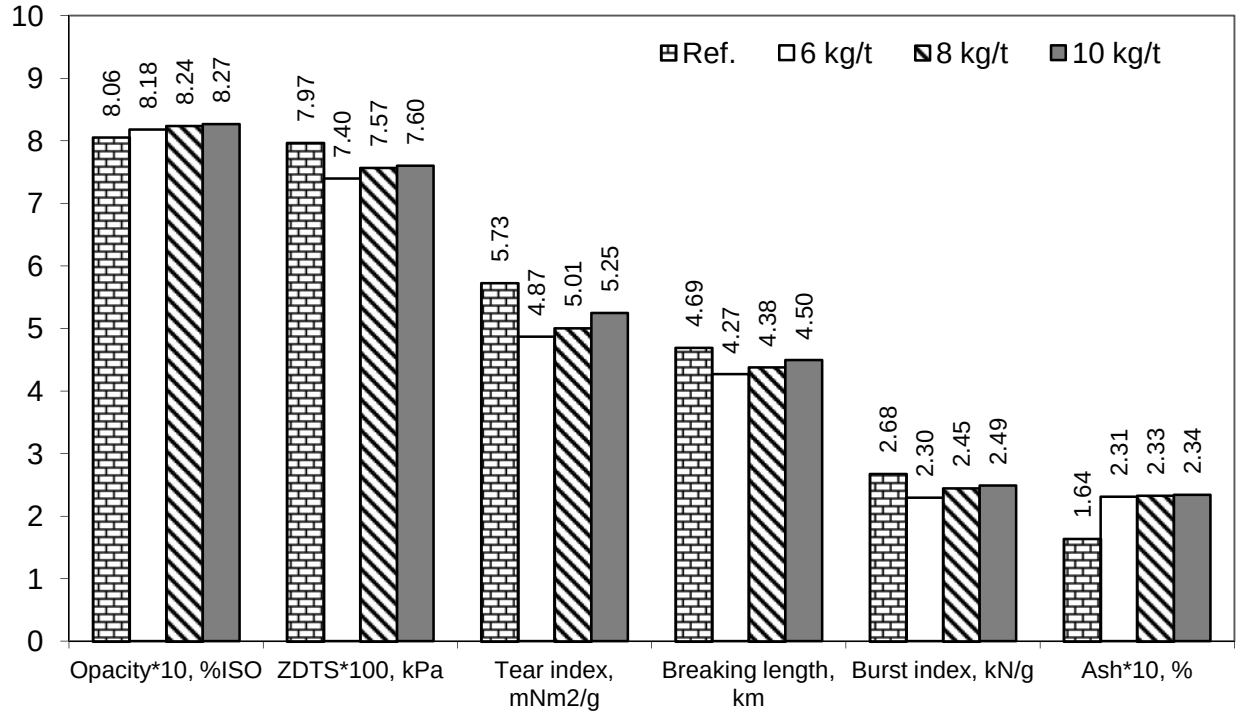

Figure 47: Effect of PS on properties of MHW pulp at 400 kg/t addition of talc

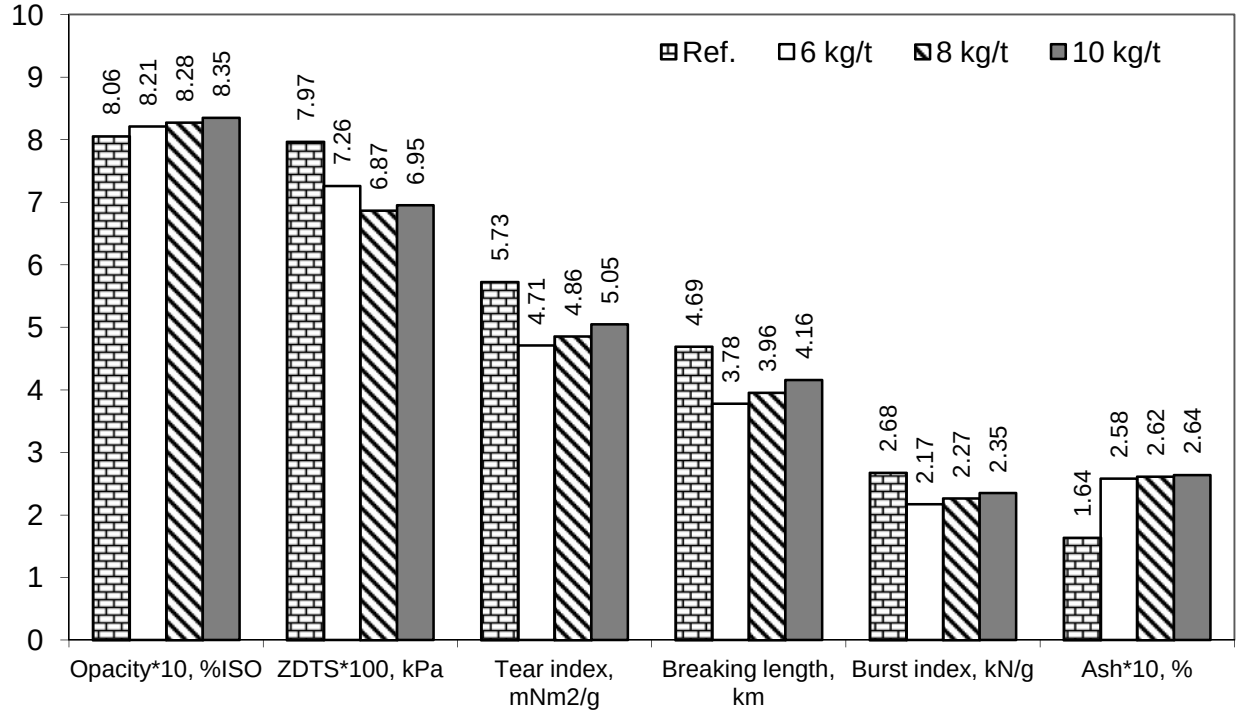

Figure 48: Effect of PS on properties of MHW pulp at 470 kg/t addition of talc

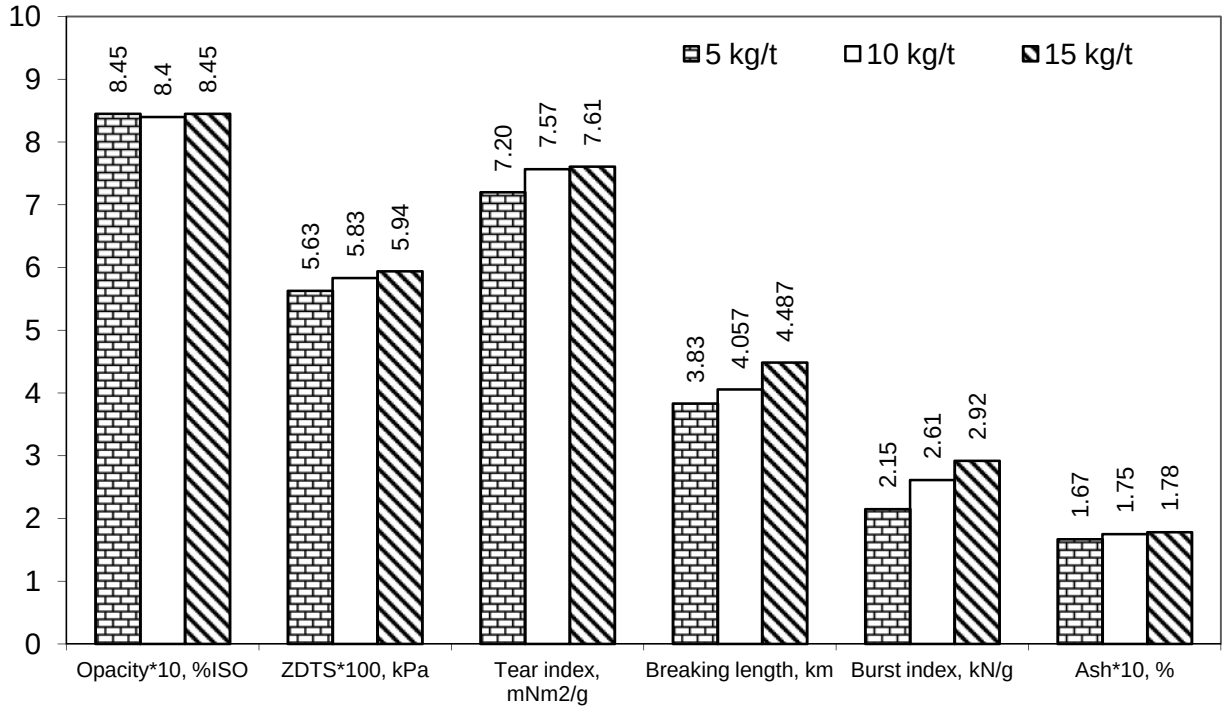

Figure 49: Effect of CS on properties of MHW pulp at 400 kg/t addition of GCC

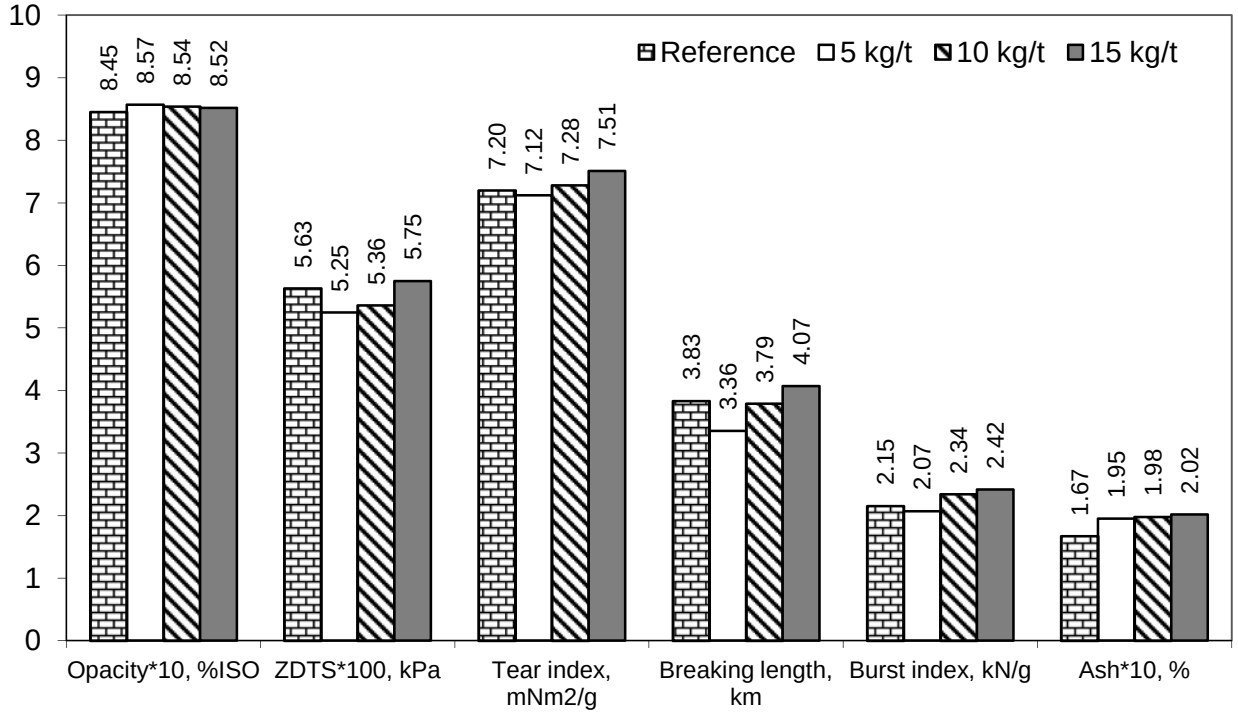

Figure 50: Effect of CS on properties of MHW pulp at 480 kg/t addition of GCC

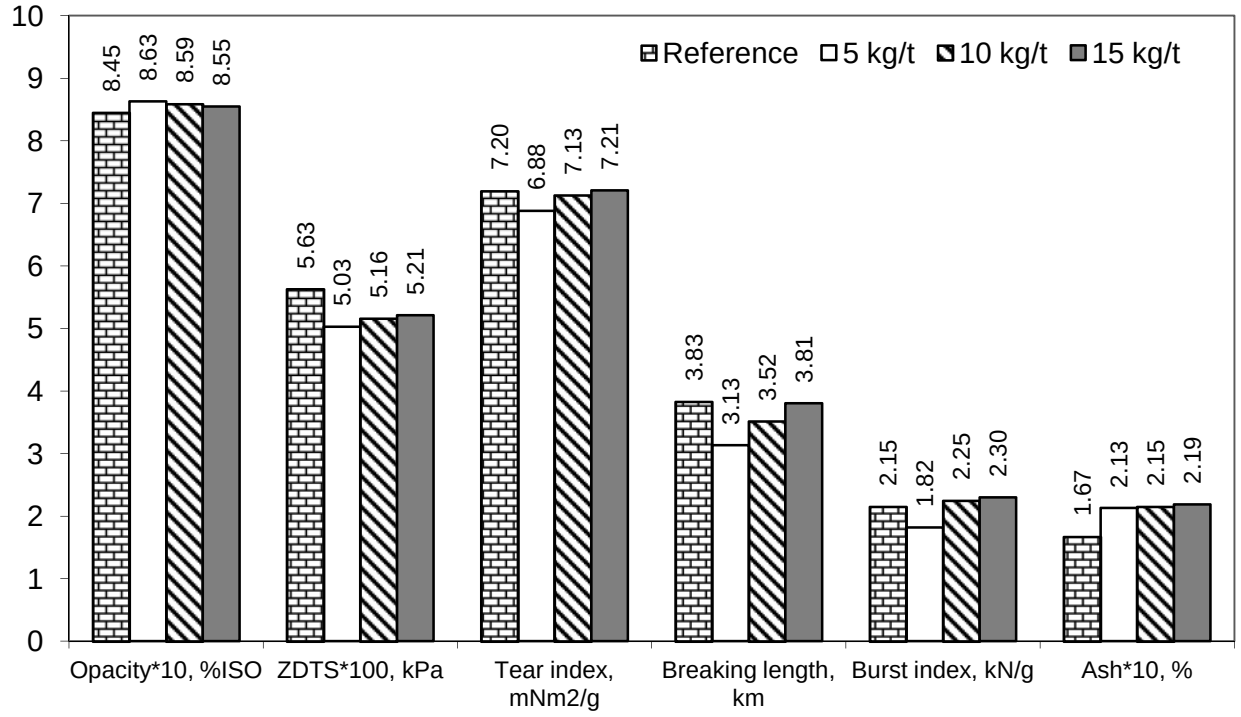

Figure 51: Effect of CS on properties of MHW pulp at 560 kg/t addition of GCC

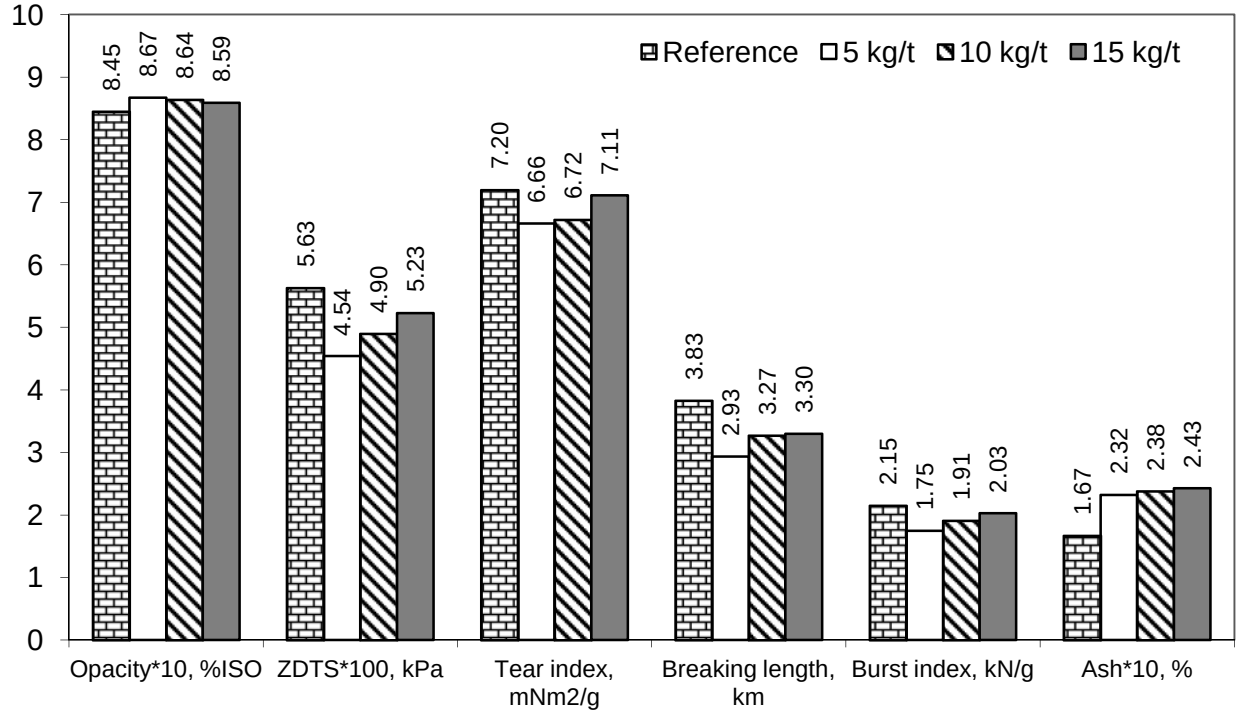

Figure 52: Effect of CS on properties of MHW pulp at 670 kg/t addition of GCC

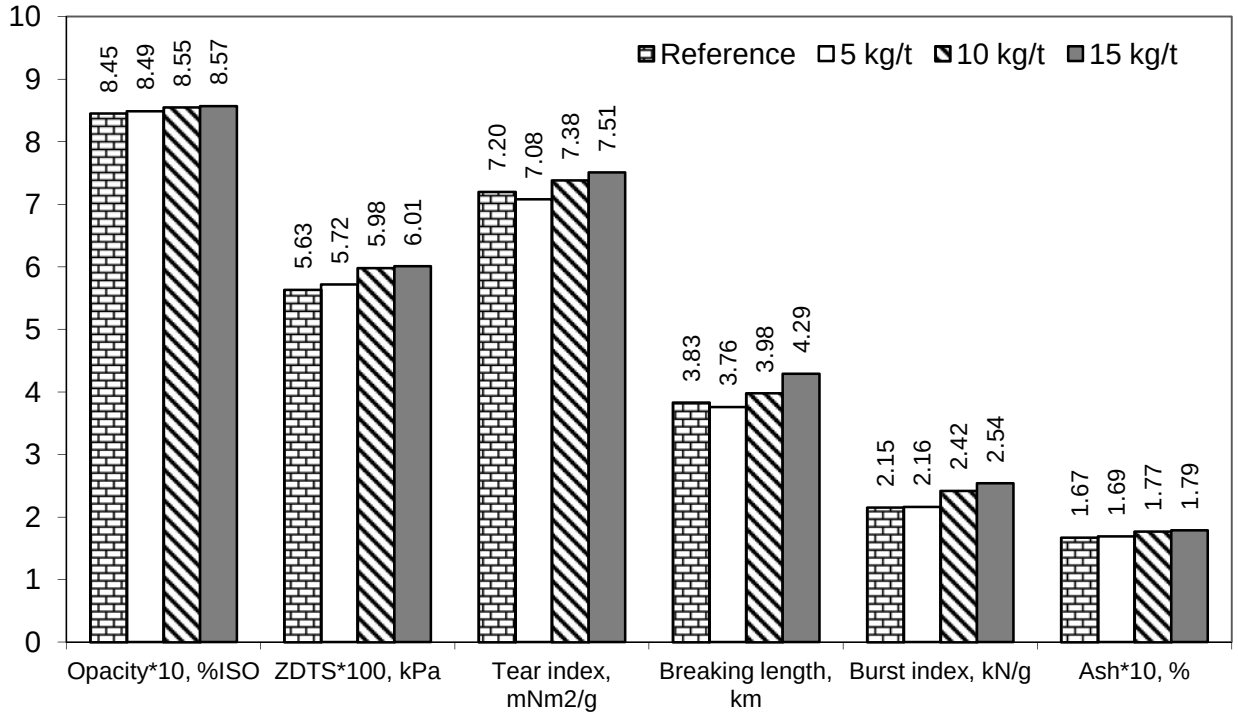

Figure 53: Effect of AS on properties of MHW pulp at 400 kg/t addition of GCC

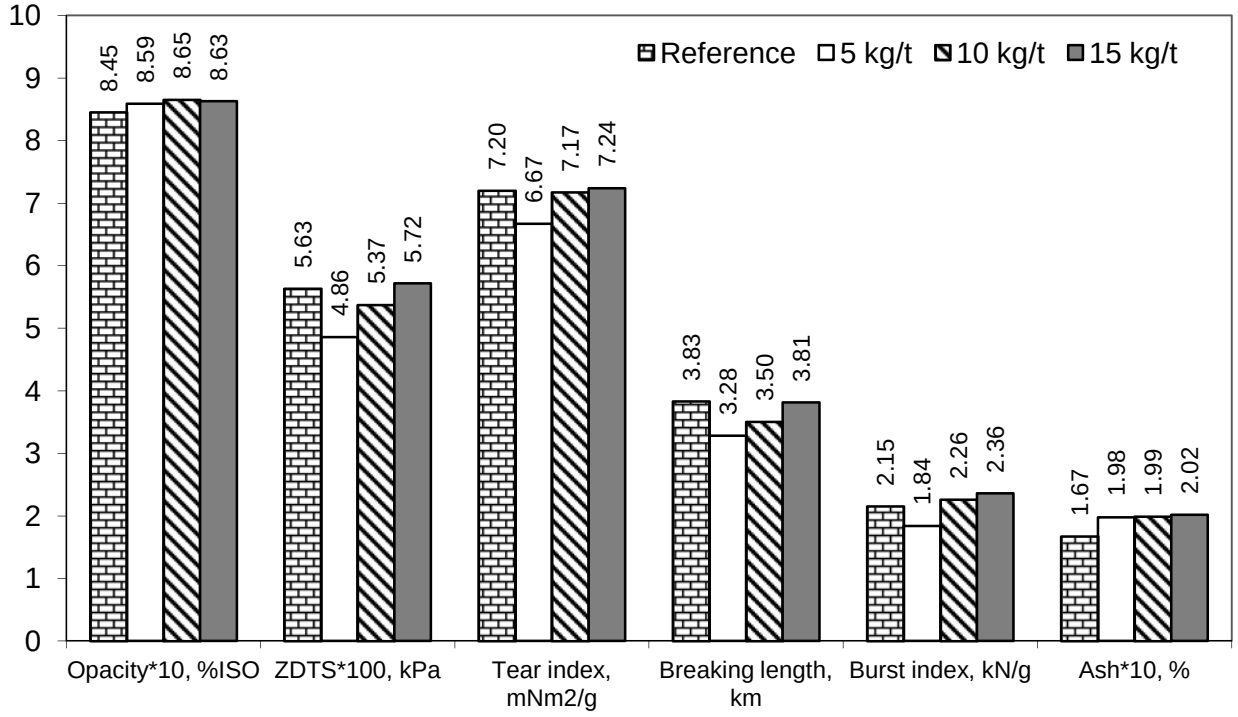

Figure 54: Effect of AS on properties of MHW pulp at 480 kg/t addition of GCC

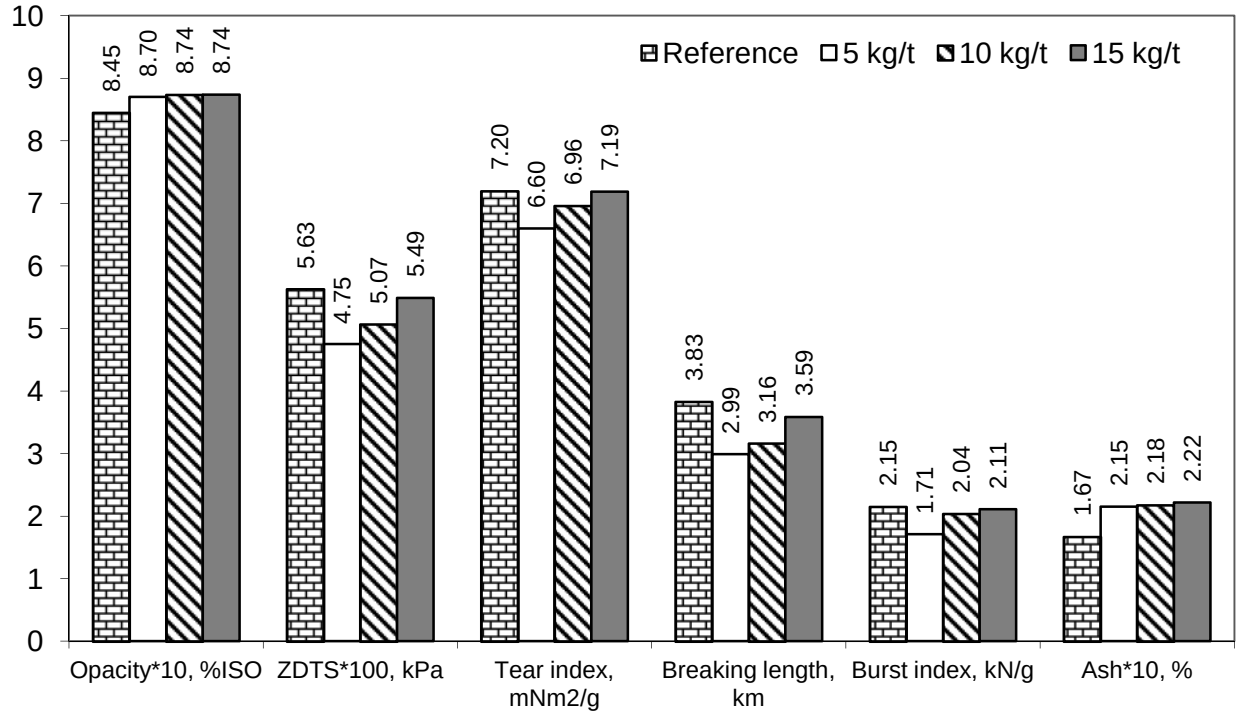

Figure 55: Effect of AS on properties of MHW pulp at 560 kg/t addition of GCC

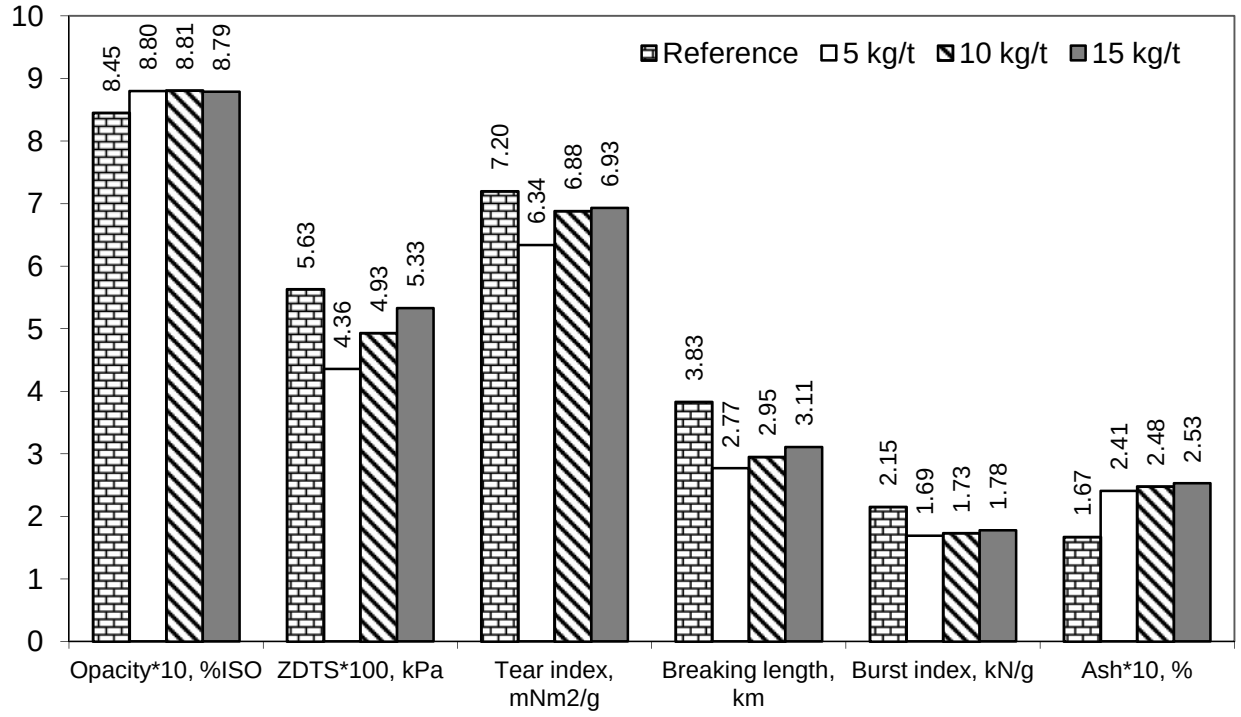

Figure 56: Effect of AS on properties of MHW pulp at 670 kg/t addition of GCC

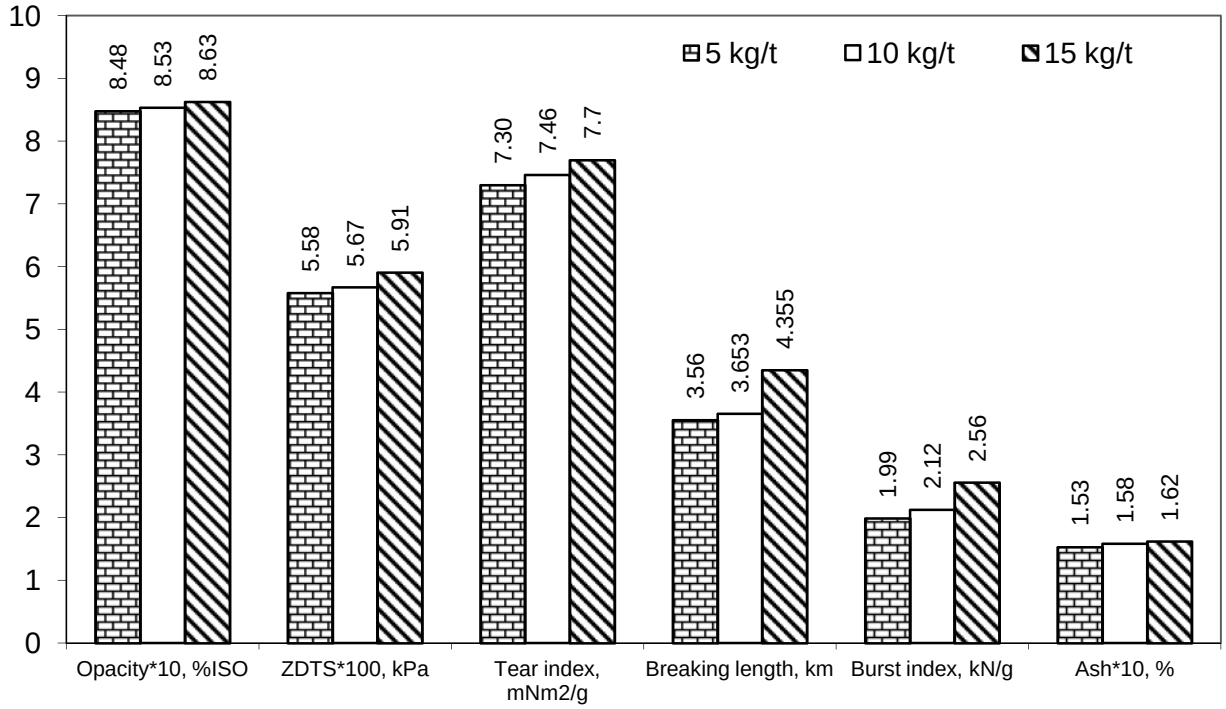

Figure 57: Effect of CS on properties of MHW pulp at 300 kg/t addition of PCC

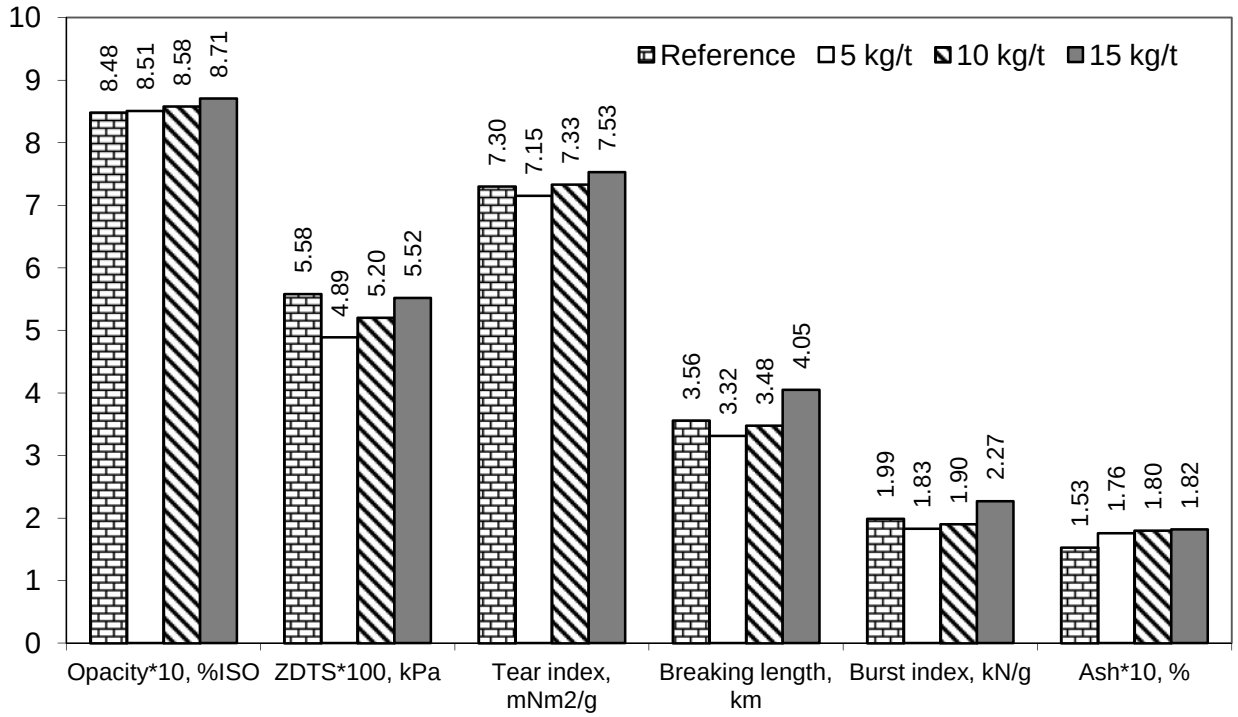

Figure 58: Effect of CS on properties of MHW pulp at 360 kg/t addition of PCC

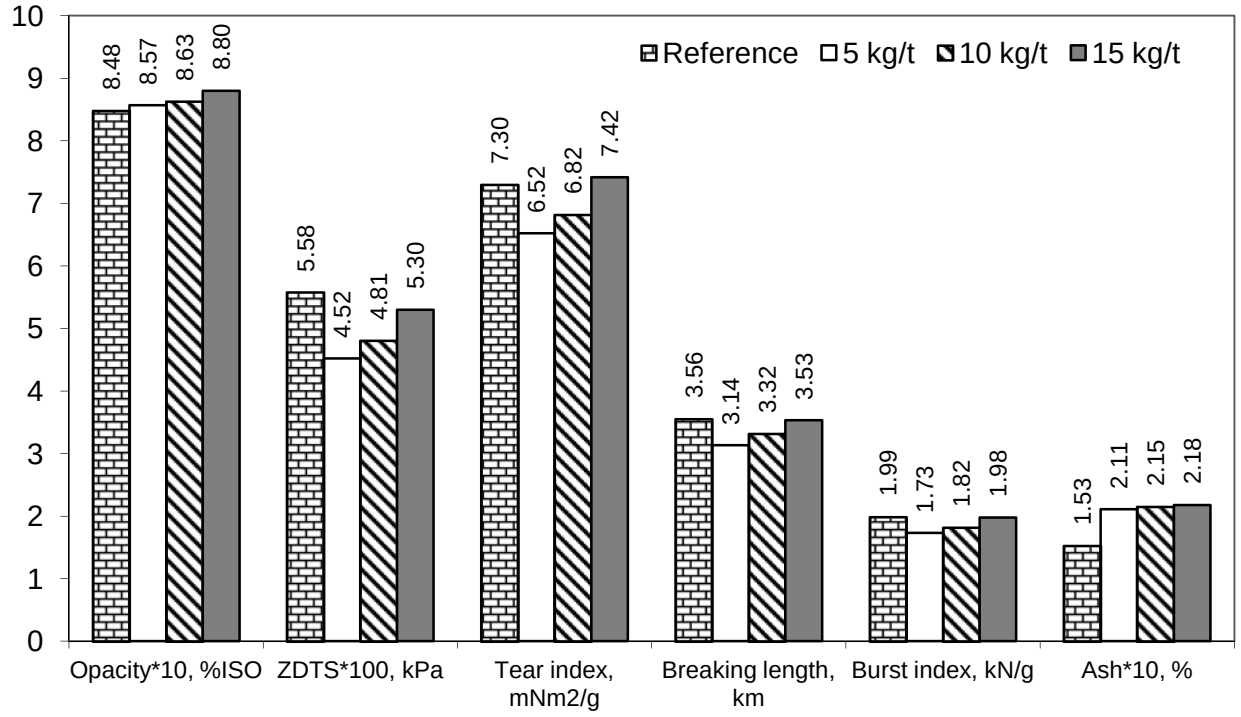

Figure 59: Effect of CS on properties of MHW pulp at 440 kg/t addition of PCC

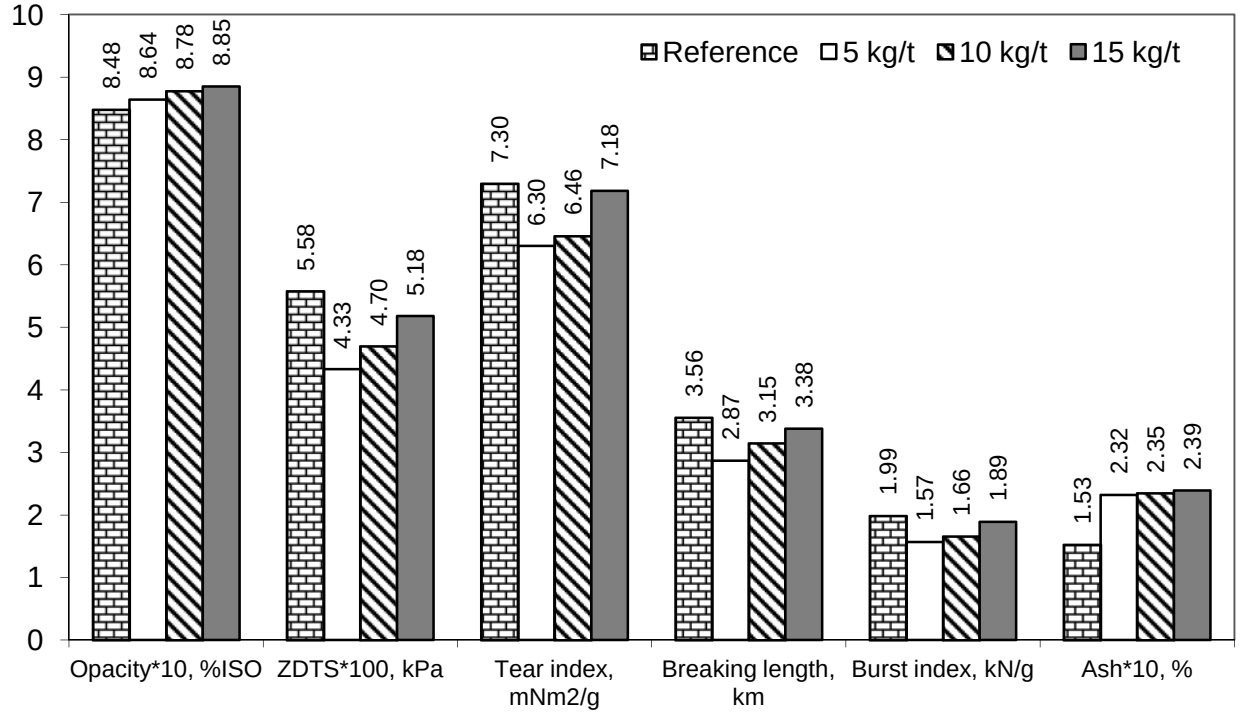

Figure 60: Effect of CS on properties of MHW pulp at 520 kg/t addition of PCC

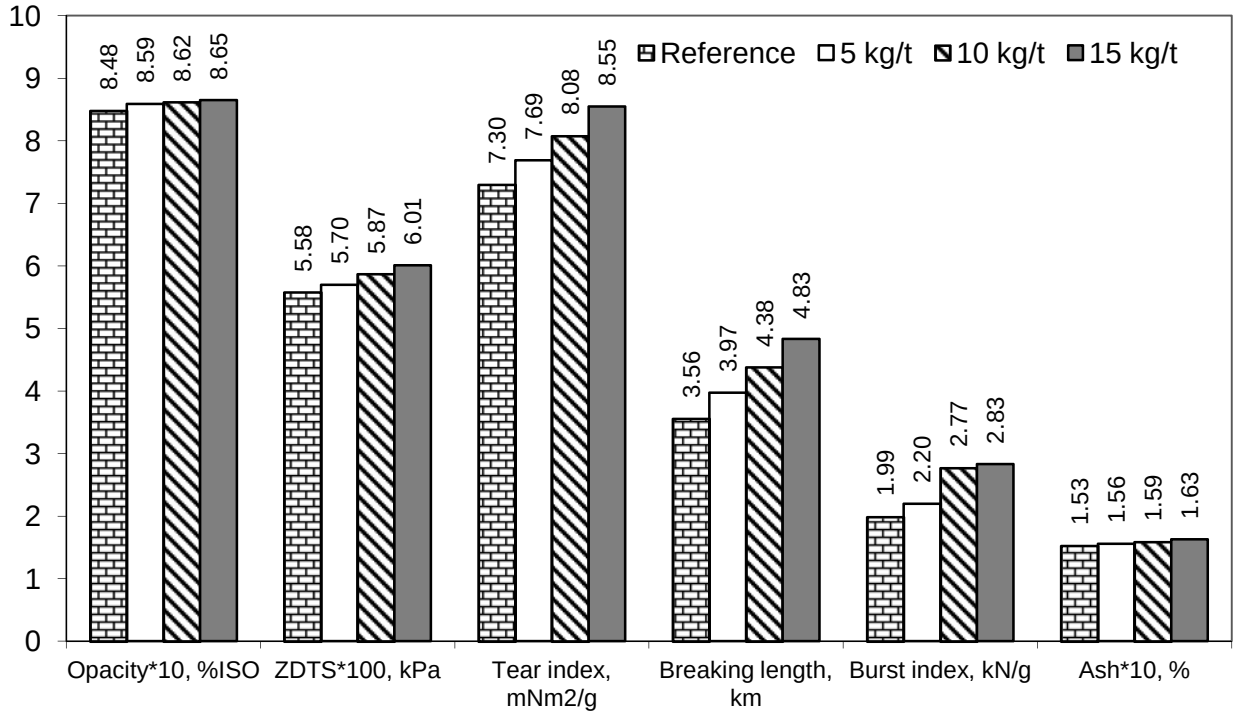

Figure 61: Effect of AS on properties of MHW pulp at 300 kg/t addition of PCC

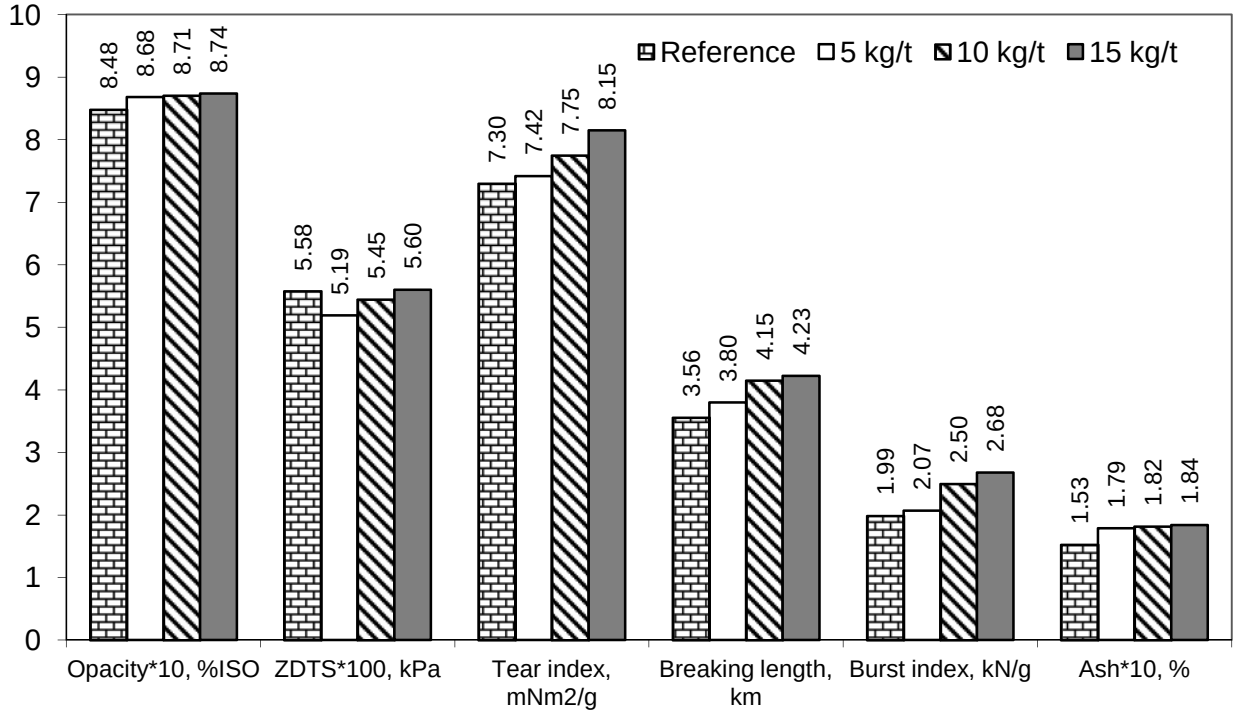

Figure 62: Effect of AS on properties of MHW pulp at 360 kg/t addition of PCC

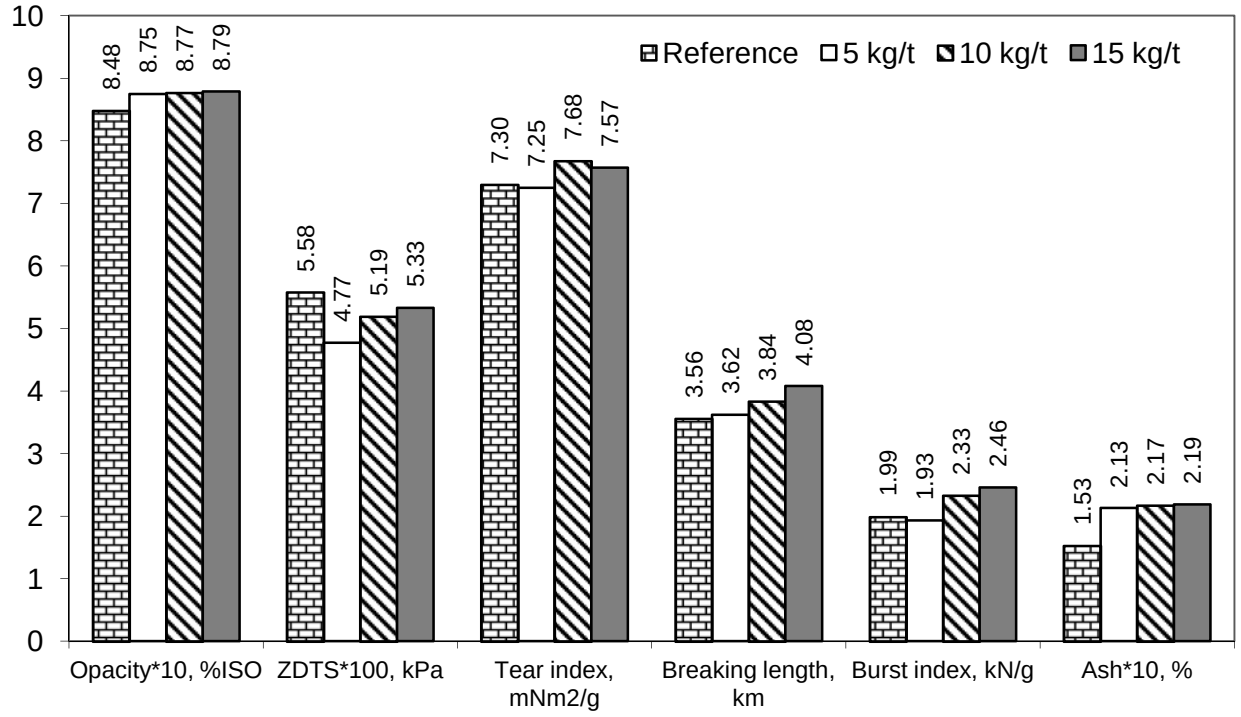

Figure 63: Effect of AS on properties of MHW pulp at 440 kg/t addition of PCC

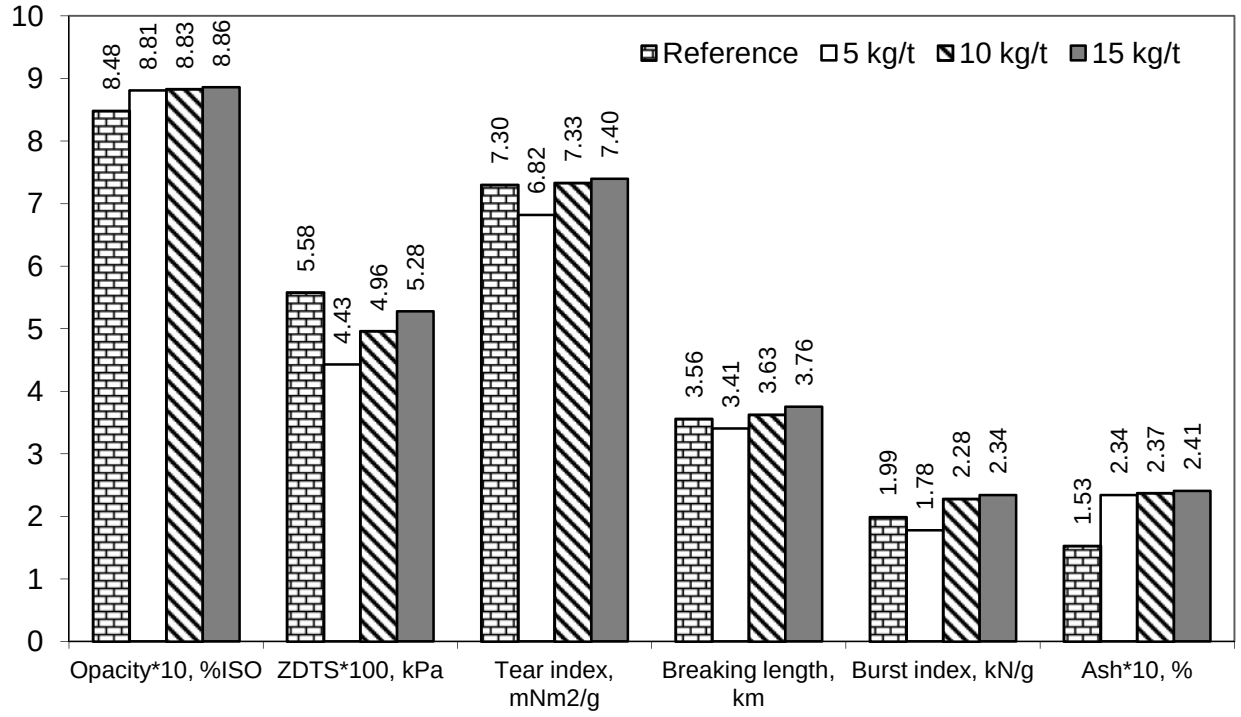

Figure 64: Effect of AS on properties of MHW pulp at 520 kg/t addition of PCC

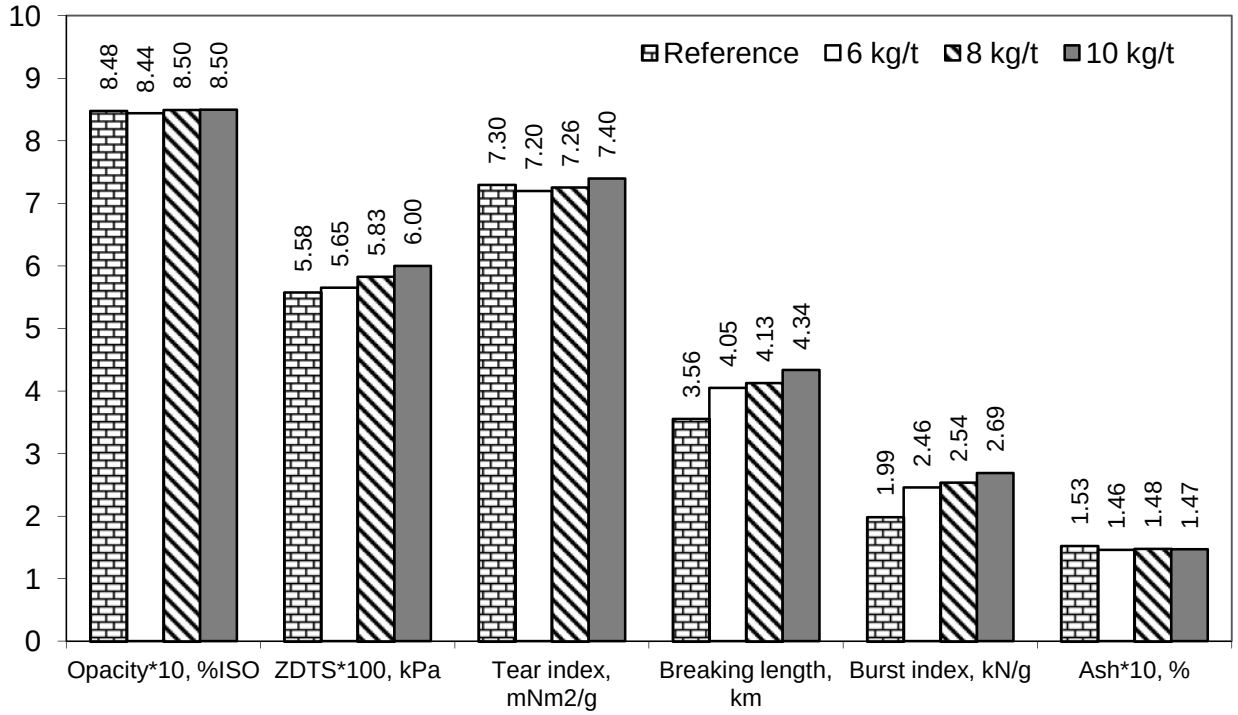

Figure 65: Effect of PS on properties of MHW pulp at 300 kg/t addition of PCC

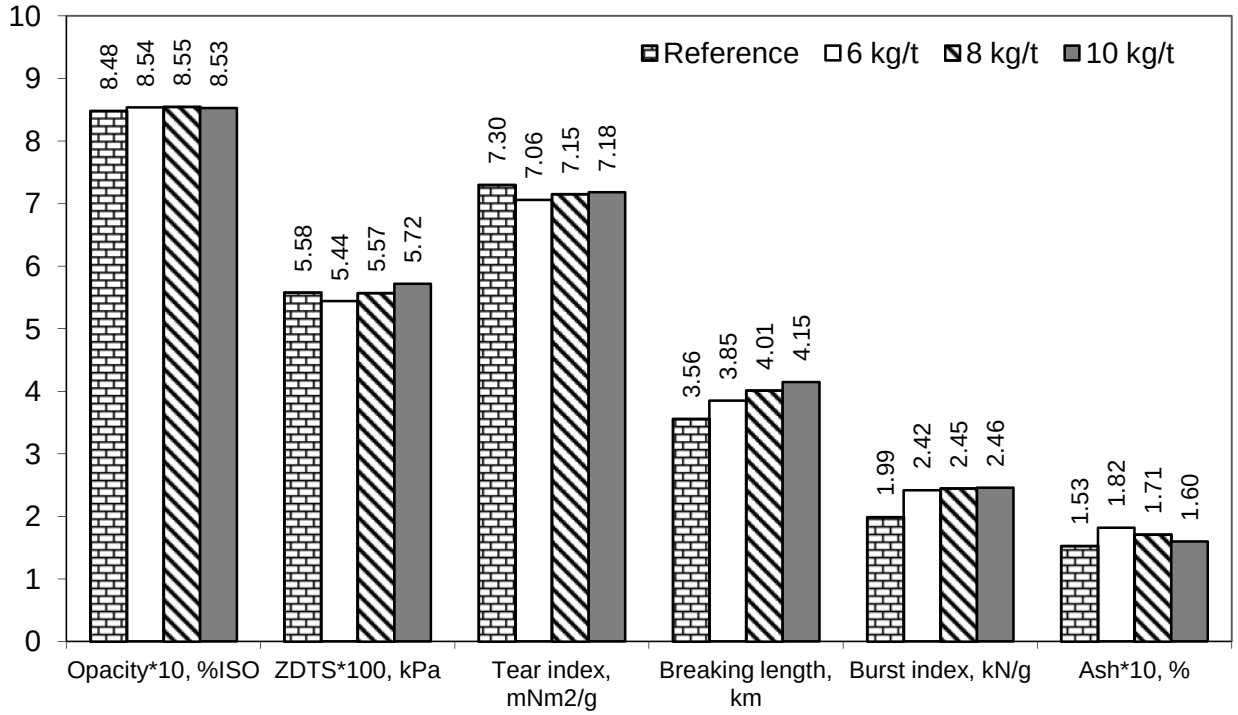

Figure 66: Effect of PS on properties of MHW pulp at 360 kg/t addition of PCC

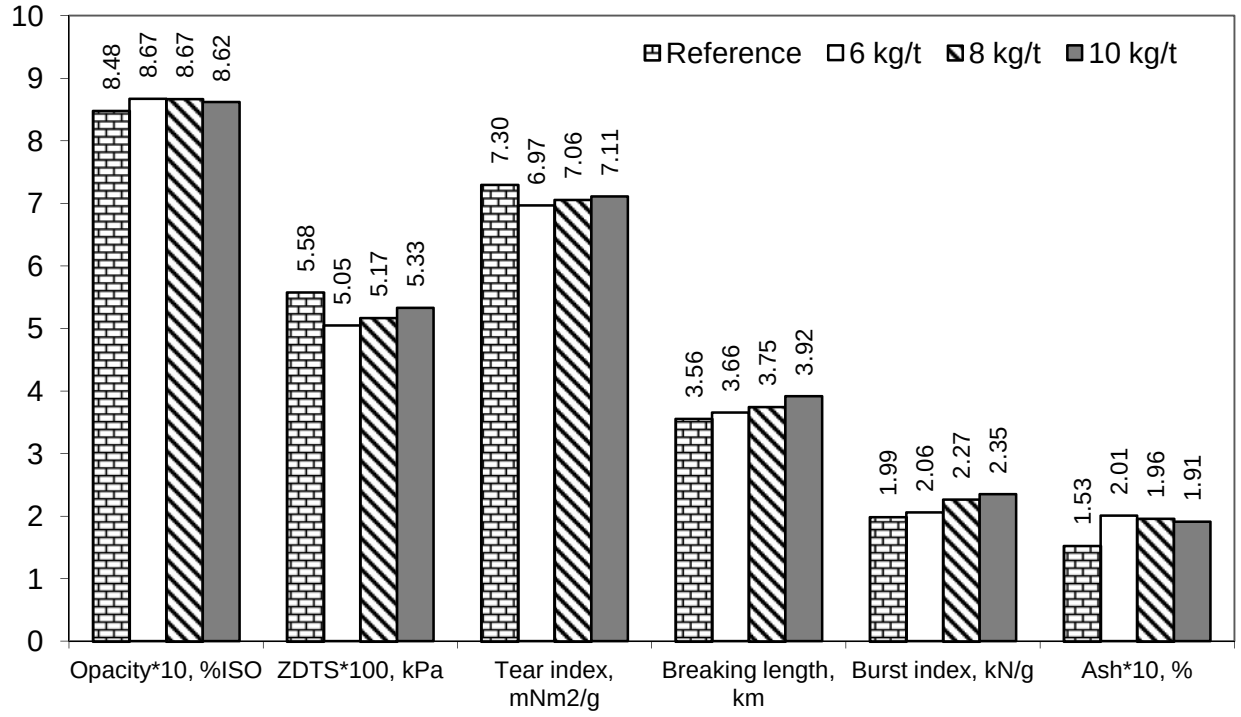

Figure 67: Effect of PS on properties of MHW pulp at 440 kg/t addition of PCC

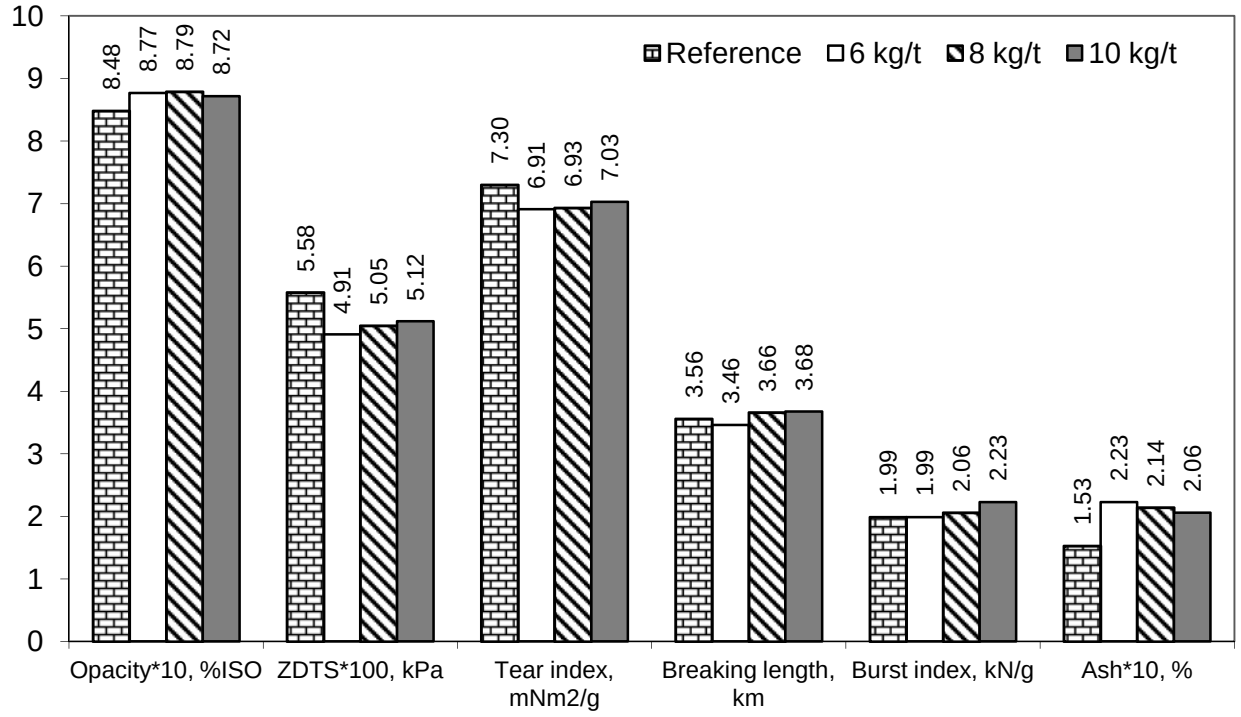

Figure 68: Effect of PS on properties of MHW pulp at 520 kg/t addition of PCC

CHAPTER – 3

Bleached Bagasse (BBS) Pulp

RESULTS & DISCUSSION

3.1. Effect of cationic strength additive and talc filler on paper

A slight mechanical action was given to BBS pulp to reform its characteristics. The freeness level of BBS was a little higher than that of mixed hardwood (MHW) and mixed hardwood blended with bamboo (MHB) pulps; it was around 480 ml whereas in case of MHW it was 430 ml. As expected with increase in dose of talc, optical properties increased at all CS doses. The cationic charge demand of pulp slurries increased with increase in talc due to the anionicity of talc. Charge demand decreased with increase in CS dose. The strength properties in case of BBS were comparatively lower than those of MHW and MHB pulps. Air permeance of paper was comparatively higher in case of BBS pulp than other pulps used (Table 62-64).

3.1.1. At 280 kg/t of Talc

There was a significant decrease in strength properties on addition of filler. At 280 kg/t addition of talc, the ash in paper was around 17% i.e. 2% higher than that of other pulps (MHW, MHB) at same talc addition levels. All strength properties were quite lower even at high CS dose. At 5 kg/t CS dose, tear index and breaking lengths were only 4.38 mNm^2/g and 2.86 km respectively which were quite low for runnability point of view. It was highly desired to blend some portion of hardwood/softwood pulp with BBS pulp to get the required strength of paper (Figure 69).

3.1.2. At 340 kg/t of Talc

At 340 kg/t addition of talc, the ash in paper was around 20.5%; around 2% higher that of other pulps at same talc addition levels. At 10 kg/t CS dose, all strength properties were comparable with reference (17% ash with 5 kg/t dose of CS). By increasing it to 15 kg/t strength properties were further improved (Figure 70).

3.1.3. At 400 kg/t of Talc

At 400 kg/t addition of talc, the ash in paper was around 23%. At 15 kg/t CS dose, all strength properties except tear index were comparable to those of reference. The drop in tear was around 3%. The gain in opacity was around 2% (Figure 71).

3.1.4. At 470 kg/t of Talc

At 470 kg/t addition of talc, the ash in paper varied from 25.1 to 26.0% on increasing the dose of CS. At this ash level, there was no much difference in strength properties of paper as compared with reference at 15 kg/t CS dose. Only tear index was lower than that of reference (Figure 72).

It was concluded that the ash in paper could be increased from 17 to 23% with 10-15 kg/t CS without affecting strength properties. BBS pulp needs blending of long fibers to maintain its runnability on paper machine.

3.2. Effect of amphoteric strength additive and talc filler on paper

The cationic charge demand of pulp slurries increased with increase in talc due to its anionic nature. The zeta potential and charge demand decrease with increase of AS dose (Table 65-67).

3.2.1. At 280 kg/t of Talc

Similar to CS, the ash in paper was around 17.5%. All strength properties were quite higher as compared with reference at all AS doses (17% ash with 5 kg/t dose of CS) (Figure 73).

3.2.2. At 340 kg/t of Talc

At 340 kg/t addition of talc, the ash in paper was around 21%. At 10 kg/t AS dose, all strength properties were higher than those of reference. By increasing the CS dose to 15 kg/t strength properties were further improved (Figure 74).

3.2.3. At 400 kg/t of Talc

At 400 kg/t addition of talc, the ash in paper was around 23.5%. At 15 kg/t AS dose, all strength properties except tear index were higher than those of reference. Tear index was comparable to reference (Figure 75).

3.2.4. At 470 kg/t of Talc

At 470 kg/t addition of talc, the ash in paper varied from 25.2 to 26.5% on increasing dose of AS. Similar to CS at this ash level also, all strength properties except tear index were comparable to those of reference. The drop in tear index was around 6% (Figure 76).

It was concluded that the ash in paper could be increased from 17 to 24% with 10-15 kg/t AS without affecting strength properties.

3.3. Effect of polymeric strength additive and talc filler on paper

The cationic charge demand of pulp slurries increased with increase in talc due to its anionic nature. The charge demand also increased with increase in PS dose (Table 68-70).

3.3.1. At 280 kg/t of Talc

The ash in paper was around 18%, 1% higher than that of reference (17% ash with 5 kg/t dose of CS). All strength properties except ZDTS were higher as compared with reference at all PS doses. ZDTS was a little lower at 6 kg/t PS dose but it was almost comparable at 8 kg/t PS dose (Figure 77).

3.3.2. At 340 kg/t of Talc

At 340 kg/t addition of talc, the ash in paper was around 20.5%. At 8 kg/t PS dose, all strength properties except ZDTS were higher than those of reference. The drop in ZDTS was around

3.5%. Moreover at 10 kg/t PS dose, all strength properties were either higher or comparable to those of reference (Figure 78).

3.3.3. At 400 kg/t of Talc

At 400 kg/t addition of talc, the ash in paper varied from 22.3 to 23.4% with increasing PS dose from 6 to 10 kg/t. At 10 kg/t PS dose, all strength properties were comparable to those of reference (Figure 79).

3.3.4. At 470 kg/t of Talc

At 470 kg/t addition of talc, the ash in paper varied from 24.6 to 25.6% on increasing dose of PS from 6 to 10 kg/t. At this ash level, all strength properties were lower than those of reference (Figure 80).

It was concluded that the ash in paper could be increased from 17 to 23% with 8-10 kg/t PS without affecting strength properties.

3.4. Effect of cationic strength additive and GCC filler on paper

3.4.1. At 400 kg/t of GCC

At this GCC addition level, the ash in paper was around 15%. All strength properties increased with increasing CS dose (Figure 81, Table 71-73).

3.4.2. At 480 kg/t of GCC

At 480 kg/t addition of GCC, the ash in paper was around 18%. At 10 kg/t CS dose, all strength properties were comparable to those of reference whereas at 15 kg/t CS dose, properties were higher than those of reference (Figure 82).

3.4.3. At 560 kg/t of GCC

At 560 kg/t addition of GCC, the ash in paper was around 21%. All strength properties were lower at 5 and 10 kg/t CS dose but at 15 kg/t CS dose, all strength properties were either comparable or higher than those of reference. The gain in opacity was 1.7 units (Figure 83).

3.4.4. At 670 kg/t of GCC

At 670 kg/t addition of GCC, the ash in paper was around 24%. At this ash level with 15 kg/t CS dose, the strength properties were a little lower than those of reference. The drop in tear index, ZDTS, breaking length and burst index were 2.0, 1.8, 5.8 and 2.5% respectively. The gain in opacity was 2.8 units (Figure 84).

It was concluded that in case of GCC filler and CS, the ash in paper could be increased from 15 to 21% with 10-15 kg/t CS without affecting strength properties.

3.5. Effect of amphoteric strength additive and GCC filler on paper

3.5.1. At 400 kg/t of GCC

The ash in paper was around 15.5%, almost similar to CS. At 5 kg/t AS dose, all strength properties were comparable to those of reference (15% ash with 5 kg/t dose of CS). With increasing dose of AS, strength properties increased (Figure 85, Table 74-76).

3.5.2. At 480 kg/t of GCC

At 480 kg/t addition of GCC, the ash in paper was around 18.5%. At 10 kg/t AS dose, all strength properties were comparable to those of reference and increased with increasing dose of AS (Figure 86).

3.5.3. At 560 kg/t of GCC

At 560 kg/t addition of GCC, the ash in paper was around 21%. All strength properties were lower at 5 and 10 kg/t AS dose but at 15 kg/t AS dose, all strength properties were comparable expect breaking length which decreased by 7.8% (Figure 87).

3.5.4. At 670 kg/t of GCC

At 670 kg/t addition of GCC, the ash in paper was around 24%. At this ash level, all strength properties were lower than those of reference (Figure 88).

It was concluded that in case of GCC filler and AS, the ash in paper could be increased from 15 to 21% with 15 kg/t AS without affecting strength properties.

3.6. Effect of cationic strength additive and PCC filler on paper

With increase in dose of PCC, the strength properties decreased whereas optical properties increased at all CS doses. The decrease in strength properties in case of PCC was higher than that with talc. The cationic charge demand of pulp slurries decreased with increase in PCC due to its cationic nature. The charge demand also decreased with increase of CS dose (Table 77-79).

3.6.1. At 300 kg/t of PCC

The ash in paper was around 18%; 3% higher than that in case of MHW and MHX pulps. All strength properties increased with increasing CS dose (Figure 89).

3.6.2. At 360 kg/t of PCC

At 360 kg/t addition of PCC, the ash in paper was around 21%. At 15 kg/t CS dose, all strength properties except tear index were higher than those of reference (18% ash with 5 kg/t dose of CS). Tear index was comparable to that of reference (Figure 90).

3.6.3. At 440 kg/t of PCC

At 440 kg/t addition of PCC, the ash in paper was around 23.5%. At 15 kg/t CS dose, burst index and ZDTS were higher but tear index and breaking length were lower than those of reference. The drop in tear index and breaking length were 3.6 and 6.4% respectively (Figure 91).

3.6.4. At 520 kg/t of PCC

At 520 kg/t addition of PCC, the ash in paper was around 25.5%. At this ash level, all strength properties were lower than those of reference (Figure 92).

It was concluded that the ash in paper could be increased from 17 to 21% with 15 kg/t CS without affecting strength properties.

3.7. Effect of amphoteric strength additive and PCC filler on paper

The cationic charge demand of pulp slurries decreased with increase in PCC due to its cationic nature. The charge demand also decreased with increase of AS dose (Table 80-82).

3.7.1. At 300 kg/t of PCC

The ash in paper was around 18.5%. At 5 kg/t AS dose, all strength properties were comparable to those of reference (18% ash with 5 kg/t dose of CS). At higher AS dose, strength properties increase further (Figure 93).

3.7.2. At 360 kg/t of PCC

At 360 kg/t addition of PCC, the ash in paper was around 21.5%. At 15 kg/t AS dose, all strength properties were either higher or comparable to those of reference (Figure 94).

3.7.3. At 440 kg/t of PCC

At 440 kg/t addition of PCC, the ash in paper was around 23.5%. All strength properties were lower at 5 and 10 kg/t AS dose but at 15 kg/t AS dose, strength properties showed different trend. Breaking length was comparable, ZDTS was higher, and tear index and burst index were lower than those of reference. The drop in tear index and burst index was around 6% (Figure 95).

3.7.4. At 520 kg/t of PCC

At 520 kg/t addition of PCC, the ash in paper was around 25.5%. At this ash level, all strength properties were lower than those of reference (Figure 96).

It was concluded that the ash in paper could be increased from 17 to 21.5% with 15 kg/t AS without affecting strength properties.

3.8. Effect of polymeric strength additive and PCC filler on paper

The ash and FPAR decrease on addition of PS with PCC filler. The ash in paper at 300 kg/t dose of PCC was 15.8% with 6 kg/t dose of PS whereas it was 18.1% with 5 kg/t dose of CS. The similar trend was also observed at other PCC addition levels. In case of PS, 360 kg/t PCC was required to get the 18% ash in paper. With increasing dose of PS, the ash and FPAR further decreased (Table 83-85).

Table 62: Properties of BBS pulp with talc and cationic strength additive at 5 kg/t

Talc addition, %	Blank*	28	34	40	47
Retained ash, %	-	17.0	20.3	23.1	25.1
FPAR, %	-	77.7	80.0	80.7	78.6
CSF, ml	480	475	485	500	510
Streaming potential, mV	-231	-93	-134	-140	-151
Charge demand, µeq/l	12.6	4.2	4.8	5.3	5.9
Zeta potential, mV	-26.3	-7.9	-8.4	-9.2	-10
Conductivity, mS	0.386	0.382	0.387	0.378	0.383
Bulk, cc/g	1.36	1.30	1.28	1.27	1.26
Breaking length, m	3754	2860	2695	2502	2431
Burst index, kN/g	2.31	1.58	1.50	1.45	1.34
Tear index, mNm^2/g	5.53	4.38	4.26	3.90	3.85
Bending stiffness, mNm	0.197	0.157	0.153	0.149	0.141
Double fold, no.	12	9	7	6	5
ZD tensile strength, kPa	685	630	614	605	590
Air permeance, Gurley s	44.0	43.3	41.5	35.8	34.6
Bendtsen roughness, ml/min	66	92	89	85	83
Brightness, %ISO	82.6	81.6	82.3	82.4	82.8
Opacity, %ISO	77.6	80.7	81.5	82.2	82.9
Scattering coefficient, m^2/kg	32.1	33.6	36.2	37.7	39.5
CIE whiteness	71.4	70.3	71.1	71.6	72.4
Yellowness	5.89	6.23	6.10	6.06	5.89
L*	95.0	94.0	94.3	94.4	94.5
a*	-0.06	0.00	0.00	-0.01	0.01
b*	3.12	3.30	3.24	3.17	3.08

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 5 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Blank: Unbeaten BBS pulp without addition of wet-end chemical*

Table 63: Properties of BBS pulp with talc and cationic strength additive at 10 kg/t

Talc addition, %	Reference*	28	34	40	47
Retained ash, %	17.0	17.2	20.6	23.2	25.3
FPAR, %	77.7	78.6	81.4	81.3	79.2
CSF, ml	475	485	490	500	520
Streaming potential, mV	-93	-106	-121	-132	-134
Charge demand, µeq/l	4.2	3.8	4.4	5.1	5.5
Zeta potential, mV	-7.9	-5.5	-7.2	-7.7	-8.0
Conductivity, mS	0.382	0.387	0.394	0.389	0.397
Bulk, cc/g	1.30	1.32	1.32	1.30	1.27
Breaking length, m	2860	3076	2862	2706	2646
Burst index, kN/g	1.58	1.78	1.65	1.50	1.42
Tear index, mNm^2/g	4.38	4.40	4.29	4.08	3.93
Bending stiffness, mNm	0.157	0.164	0.154	0.151	0.144
Double fold, no.	9	11	8	7	6
ZD tensile strength, kPa	630	659	645	629	619
Air permeance, Gurley s	43.3	38.8	39.1	38.3	38.6
Bendtsen roughness, ml/min	92	88	87	85	81
Brightness, %ISO	81.6	81.4	81.8	81.9	82.4
Opacity, %ISO	80.7	81.0	82.0	82.4	82.8
Scattering coefficient, m^2/kg	33.6	34.1	36.5	37.4	38.9
CIE whiteness	70.3	70.6	70.9	71.0	71.7
Yellowness	6.23	6.33	6.28	6.28	6.11
L*	94.0	94.2	94.3	94.3	94.4
a*	0.00	0.01	0.00	0.01	0.02
b*	3.30	3.35	3.28	3.18	3.12

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 10 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BBS with talc and CS, 5 kg/t at 17% ash level*

Table 64: Properties of BBS pulp with talc and cationic strength additive at 15 kg/t

Talc addition, %	Reference*	28	34	40	47
Retained ash, %	17.0	17.4	20.9	23.5	26.0
FPAR, %	77.7	79.8	82.4	82.3	81.4
CSF, ml	475	490	500	515	525
Streaming potential, mV	-93	-78	-68	-57	-48
Charge demand, µeq/l	4.2	3.6	4.2	4.8	5.1
Zeta potential, mV	-7.9	-3.1	-4.1	-5.8	-6.5
Conductivity, mS	0.382	0.397	0.398	0.394	0.394
Bulk, cc/g	1.30	1.33	1.32	1.30	1.27
Breaking length, m	2860	3144	3060	2834	2758
Burst index, kN/g	1.58	1.90	1.80	1.68	1.54
Tear index, mNm^2/g	4.38	4.95	4.35	4.24	4.17
Bending stiffness, mNm	0.157	0.173	0.157	0.154	0.149
Double fold, no.	9	12	9	9	7
ZD tensile strength, kPa	630	688	654	639	628
Air permeance, Gurley s	43.3	42.5	40.9	40.1	38.0
Bendtsen roughness, ml/min	92	85	84	82	78
Brightness, %ISO	81.6	81.2	81.5	81.8	82.2
Opacity, %ISO	80.7	81.1	81.7	82.1	82.4
Scattering coefficient, m^2/kg	33.6	34.0	36.0	37.8	38.8
CIE whiteness	70.3	71.0	71.5	71.8	72.0
Yellowness	6.23	6.47	6.42	6.37	6.29
L*	94.0	94.1	94.1	94.3	94.3
a*	0.00	0.05	0.04	0.02	0.05
b*	3.30	3.43	3.41	3.33	3.32

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 15 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BBS with talc and CS, 5 kg/t at 17% ash level*

Table 65: Properties of BBS pulp with talc and amphoteric strength additive at 5 kg/t

Talc addition, %	Reference*	28	34	40	47
Retained ash, %	17.0	17.2	20.5	23.3	25.2
FPAR, %	77.7	78.8	80.8	81.5	79.0
CSF, ml	475	485	495	510	525
Streaming potential, mV	-93	-75	-84	-88	-92
Charge demand, µeq/l	4.2	4.2	4.4	4.8	5.1
Zeta potential, mV	-7.9	-3.9	-4.2	-5.1	-5.8
Conductivity, mS	0.382	0.402	0.405	0.406	0.406
Bulk, cc/g	1.30	1.31	1.29	1.29	1.26
Breaking length, m	2860	3263	2958	2848	2618
Burst index, kN/g	1.58	1.77	1.66	1.47	1.44
Tear index, mNm^2/g	4.38	4.29	4.15	3.96	3.85
Bending stiffness, mNm	0.157	0.154	0.148	0.137	0.121
Double fold, no.	9	10	8	7	5
ZD tensile strength, kPa	630	656	631	619	602
Air permeance, Gurley s	43.3	45.4	40.8	38.9	33.7
Bendtsen roughness, ml/min	92	99	97	90	81
Brightness, %ISO	81.6	81.3	81.6	81.9	82.1
Opacity, %ISO	80.7	81.6	82.0	82.7	83.0
Scattering coefficient, m^2/kg	33.6	35.8	36.9	38.6	39.9
CIE whiteness	70.3	68.4	69.6	69.9	70.7
Yellowness	6.23	6.48	6.43	6.52	6.17
L*	94.0	94.0	94.1	94.2	94.3
a*	0.00	0.05	0.07	0.06	0.07
b*	3.30	3.36	3.31	3.25	3.24

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 5 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BBS with talc and CS, 5 kg/t at 17% ash level*

Table 66: Properties of BBS pulp with talc and amphoteric strength additive at 10 kg/t

Talc addition, %	Reference*	28	34	40	47
Retained ash, %	17.0	17.6	20.9	23.7	25.6
FPAR, %	77.7	80.3	82.3	82.8	80.2
CSF, ml	475	490	500	515	525
Streaming potential, mV	-93	-50	-65	-75	-80
Charge demand, µeq/l	4.2	3.3	3.6	3.8	3.9
Zeta potential, mV	-7.9	-1.9	-2.8	-3.2	-3.8
Conductivity, mS	0.382	0.404	0.409	0.408	0.405
Bulk, cc/g	1.30	1.32	1.30	1.28	1.25
Breaking length, m	2860	3488	3178	2929	2660
Burst index, kN/g	1.58	1.83	1.74	1.68	1.50
Tear index, mNm^2/g	4.38	4.82	4.43	4.20	4.05
Bending stiffness, mNm	0.157	0.158	0.153	0.145	0.134
Double fold, no.	9	12	9	9	7
ZD tensile strength, kPa	630	684	649	620	612
Air permeance, Gurley s	43.3	42.9	39.8	37.3	34.2
Bendtsen roughness, ml/min	92	94	92	86	80
Brightness, %ISO	81.6	81.1	81.5	81.7	82.0
Opacity, %ISO	80.7	81.1	81.6	82.0	82.4
Scattering coefficient, m^2/kg	33.6	35.1	35.9	37.6	39.0
CIE whiteness	70.3	69.9	70.3	70.3	71.4
Yellowness	6.23	6.45	6.34	6.21	6.21
L*	94.0	94.0	94.1	94.2	94.4
a*	0.00	0.03	0.07	0.03	0.00
b*	3.30	3.69	3.54	3.42	3.37

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 10 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BBS with talc and CS, 5 kg/t at 17% ash level*

Table 67: Properties of BBS pulp with talc and amphoteric strength additive at 15 kg/t

Talc addition, %	Reference*	28	34	40	47
Retained ash, %	17.0	17.8	21.1	24.0	26.5
FPAR, %	77.7	81.3	83.2	84.0	81.8
CSF, ml	475	495	505	520	530
Streaming potential, mV	-93	-30	-45	-50	-62
Charge demand, µeq/l	4.2	3.0	3.2	3.4	3.5
Zeta potential, mV	-7.9	-1.7	-1.6	-1.8	-2.5
Conductivity, mS	0.382	0.406	0.406	0.408	0.406
Bulk, cc/g	1.30	1.32	1.30	1.28	1.25
Breaking length, m	2860	3527	3282	3007	2876
Burst index, kN/g	1.58	2.10	1.93	1.85	1.61
Tear index, mNm^2/g	4.38	5.09	4.60	4.32	4.11
Bending stiffness, mNm	0.157	0.162	0.161	0.151	0.144
Double fold, no.	9	13	11	11	8
ZD tensile strength, kPa	630	729	682	646	626
Air permeance, Gurley s	43.3	45.8	43.4	40.6	35.6
Bendtsen roughness, ml/min	92	88	85	85	80
Brightness, %ISO	81.6	81.0	81.3	81.5	81.8
Opacity, %ISO	80.7	81.0	81.4	81.7	82.2
Scattering coefficient, m^2/kg	33.6	35.4	36.0	36.4	38.3
CIE whiteness	70.3	70.4	70.9	71.6	73.4
Yellowness	6.23	6.41	6.28	6.21	6.15
L*	94.0	94.2	94.3	94.4	94.5
a*	0.00	0.03	0.01	0.02	0.03
b*	3.30	3.81	3.66	3.48	3.40

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 15 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BBS with talc and CS, 5 kg/t at 17% ash level*

Table 68: Properties of BBS pulp with talc and polymeric strength additive at 6 kg/t

Talc addition, %	Reference*	28	34	40	47
Retained ash, %	17.0	17.9	20.3	22.3	24.6
FPAR, %	77.7	81.7	79.9	78.1	76.9
CSF, ml	475	385	395	415	425
Streaming potential, mV	-93	-100	-105	-110	-120
Charge demand, µeq./l	4.2	4.0	4.9	5.8	7.4
Zeta potential, mV	-7.9	-7.7	-8.4	-8.6	-9.0
Conductivity, mS	0.382	0.424	0.419	0.423	0.425
Bulk, cc/g	1.30	1.30	1.29	1.28	1.28
Breaking length, m	2860	2840	2677	2498	2264
Burst index, kN/g	1.58	1.55	1.51	1.31	1.15
Tear index, mNm^2/g	4.38	4.42	4.17	3.86	3.71
Bending stiffness, mNm	0.157	0.134	0.131	0.125	0.120
Double fold, no.	9	6	5	4	3
ZD tensile strength, kPa	630	576	565	543	518
Air permeance, Gurley s	43.3	44.7	38.4	37.1	33.8
Bendtsen roughness, ml/min	92	84	82	81	72
Brightness, %ISO	81.6	80.8	81.9	82.0	82.3
Opacity, %ISO	80.7	79.9	81.4	81.5	82.5
Scattering coefficient, m^2/kg	33.6	34.4	35.9	36.9	38.3
CIE whiteness	70.3	69.6	70.6	71.1	71.6
Yellowness	6.23	6.37	6.32	6.33	6.13
L*	94.0	94.0	94.3	94.3	94.4
a*	0.00	0.10	0.10	0.09	0.08
b*	3.30	3.28	3.26	3.27	3.17

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + PS, 6 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BBS with talc and CS, 5 kg/t at 17% ash level*

Table 69: Properties of BBS pulp with talc and polymeric strength additive at 8 kg/t

Talc addition, %	Reference*	28	34	40	47
Retained ash, %	17	18.3	20.6	22.7	25.1
FPAR, %	77.7	83.5	81.0	79.4	78.5
CSF, ml	475	415	430	445	460
Streaming potential, mV	-93	-102	-105	-113	-122
Charge demand, µeq/l	4.2	6.3	7.4	8.8	10.2
Zeta potential, mV	-7.9	-8.1	-8.8	-9.1	-10.2
Conductivity, mS	0.382	0.433	0.424	0.431	0.431
Bulk, cc/g	1.30	1.30	1.28	1.27	1.27
Breaking length, m	2860	3002	2895	2798	2471
Burst index, kN/g	1.58	1.67	1.61	1.49	1.33
Tear index, mNm^2/g	4.38	4.65	4.48	4.22	4.01
Bending stiffness, mNm	0.157	0.140	0.137	0.128	0.122
Double fold, no.	9	8	7	5	5
ZD tensile strength, kPa	630	626	607	602	584
Air permeance, Gurley s	43.3	46.9	40.8	39.8	35.1
Bendtsen roughness, ml/min	92	75	73	71	70
Brightness, %ISO	81.6	80.5	81.4	81.7	82.1
Opacity, %ISO	80.7	80.2	80.8	81.0	82.0
Scattering coefficient, m^2/kg	33.6	33.8	35.0	36.8	37.8
CIE whiteness	70.3	69.6	70.7	71.2	71.5
Yellowness	6.23	6.56	6.59	6.27	6.22
L*	94.0	93.9	94.2	94.3	94.4
a*	0.00	0.07	0.11	0.08	0.06
b*	3.30	3.39	3.40	3.25	3.22

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + PS, 8 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BBS with talc and CS, 5 kg/t at 17% ash level*

Table 70: Properties of BBS pulp with talc and polymeric strength additive at 10 kg/t

Talc addition, %	Reference*	28	34	40	47
Retained ash, %	17.0	18.4	20.9	23.4	25.6
FPAR, %	77.7	84.0	82.3	81.9	81.6
CSF, ml	475	450	455	475	485
Streaming potential, mV	-93	-115	-120	-115	-123
Charge demand, µeq/l	4.2	8.2	9.4	11.0	12.8
Zeta potential, mV	-7.9	-8.8	-9.5	-10.2	-11.5
Conductivity, mS	0.382	0.435	0.426	0.433	0.435
Bulk, cc/g	1.30	1.30	1.28	1.27	1.26
Breaking length, m	2860	3263	3055	2866	2582
Burst index, kN/g	1.58	1.95	1.65	1.57	1.42
Tear index, mNm^2/g	4.38	4.88	4.51	4.38	4.06
Bending stiffness, mNm	0.157	0.155	0.141	0.132	0.127
Double fold, no.	9	10	9	8	7
ZD tensile strength, kPa	630	659	635	619	603
Air permeance, Gurley s	43.3	48.8	42.7	41.6	37.4
Bendtsen roughness, ml/min	92	78	72	69	66
Brightness, %ISO	81.6	80.3	80.8	80.6	80.2
Opacity, %ISO	80.7	81.0	81.3	81.7	82.0
Scattering coefficient, m^2/kg	33.6	34.1	35.5	36.7	37.1
CIE whiteness	70.3	70.1	71.0	71.2	71.8
Yellowness	6.23	6.53	6.30	6.36	6.09
L*	94.0	93.9	94.1	94.2	94.3
a*	0.00	0.11	0.12	0.10	0.09
b*	3.30	3.56	3.42	3.28	3.25

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + PS, 10 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BBS with talc and CS, 5 kg/t at 17% ash level*

Table 71: Properties of BBS pulp with GCC and cationic strength additive at 5 kg/t

GCC addition, %	Blank*	40	48	56	67
Retained ash, %	-	14.8	17.9	20.6	23.7
FPAR, %	-	51.8	55.2	57.3	59.1
CSF, ml	480	540	550	550	560
Streaming potential, mV	-231	-220	-212	-180	-178
Charge demand, µeq/l	12.6	10.8	9.5	7.4	7.1
Zeta potential, mV	-26.3	-8.3	-8.0	-6.7	-6.2
Conductivity, mS	0.386	0.419	0.42	0.441	0.437
Bulk, cc/g	1.36	1.33	1.32	1.28	1.31
Breaking length, m	4002	3085	2928	2731	2471
Burst index, kN/g	2.34	1.59	1.36	1.35	1.33
Tear index, mNm^2/g	5.53	4.98	4.75	4.54	3.64
Bending stiffness, mNm	0.197	0.137	0.122	0.114	0.136
Double fold, no.	12	7	6	4	5
ZD tensile strength, kPa	685	601	585	559	571
Air permeance, Gurley s	43.0	42.5	36.7	35.5	25.4
Bendtsen roughness, ml/min	66	85	78	81	87
Brightness, %ISO	82.6	84.4	85.2	85.4	87.3
Opacity, %ISO	77.6	85.1	85.8	86.7	87.5
Scattering coefficient, m^2/kg	32.1	44.9	45.5	48.5	55.9
CIE whiteness	71.4	75.1	76.3	76.7	79.5
Yellowness	5.89	5.35	5.13	4.96	4.54
L*	95.0	95.2	95.4	95.4	96.1
a*	-0.06	0.00	-0.02	0.00	-0.01
b*	3.12	2.84	2.71	2.61	2.40

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 5 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Blank: Unbeaten BBS pulp without addition of wet-end chemical*

Table 72: Properties of BBS pulp with GCC and cationic strength additive at 10 kg/t

GCC addition, %	Reference*	40	48	56	67
Retained ash, %	14.8	15.1	18.2	20.9	24.0
FPAR, %	51.8	53.0	56.1	58.1	59.8
CSF, ml	540	550	570	590	610
Streaming potential, mV	-220	-192	-182	-175	-167
Charge demand, µeq/l	10.8	8.4	8.1	7	7.3
Zeta potential, mV	-8.3	-4.7	-4.7	-3.8	-4.1
Conductivity, mS	0.419	0.446	0.449	0.436	0.428
Bulk, cc/g	1.33	1.33	1.32	1.29	1.32
Breaking length, m	3085	3325	3144	2860	2580
Burst index, kN/g	1.59	1.70	1.48	1.45	1.53
Tear index, mNm^2/g	4.98	5.25	4.84	4.76	3.92
Bending stiffness, mNm	0.137	0.147	0.131	0.127	0.118
Double fold, no.	7	9	7	6	5
ZD tensile strength, kPa	601	622	603	579	590
Air permeance, Gurley s	42.5	41.3	36.2	37.0	25.3
Bendtsen roughness, ml/min	85	82	75	78	87
Brightness, %ISO	84.4	84.4	84.1	85.3	86.9
Opacity, %ISO	85.1	85.4	86.0	87.1	87.5
Scattering coefficient, m^2/kg	44.9	45.7	46.1	50.6	55.8
CIE whiteness	75.1	75.0	75.9	76.3	78.9
Yellowness	5.35	5.62	5.37	5.03	4.62
L*	95.2	95.2	95.3	95.5	95.9
a*	0.00	-0.03	-0.03	-0.06	-0.01
b*	2.84	2.97	2.83	2.68	2.44

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 10 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BBS with GCC and CS, 5 kg/t at 15% ash level*

Table 73: Properties of BBS pulp with GCC and cationic strength additive at 15 kg/t

GCC addition, %	Reference*	40	48	56	67
Retained ash, %	14.8	15.3	18.5	21.1	23.4
FPAR, %	51.8	53.4	57.0	58.8	58.3
CSF, ml	540	500	505	510	510
Streaming potential, mV	-220	-175	-160	-151	-141
Charge demand, µeq/l	10.8	8.1	7.4	6.9	6.1
Zeta potential, mV	-8.3	-5.3	-4.2	-3.3	-2.7
Conductivity, mS	0.419	0.437	0.436	0.451	0.452
Bulk, cc/g	1.33	1.32	1.32	1.31	1.30
Breaking length, m	3085	3480	3330	3085	2906
Burst index, kN/g	1.59	1.87	1.76	1.60	1.55
Tear index, mNm^2/g	4.98	5.64	5.48	5.14	4.88
Bending stiffness, mNm	0.137	0.178	0.154	0.142	0.134
Double fold, no.	7	13	10	8	5
ZD tensile strength, kPa	601	660	636	615	590
Air permeance, Gurley s	42.5	43.2	40.2	36.6	36.4
Bendtsen roughness, ml/min	85	83	79	75	71
Brightness, %ISO	84.4	83.9	84.3	84.1	85.0
Opacity, %ISO	85.1	85.1	85.9	86.8	87.9
Scattering coefficient, m^2/kg	44.9	44.6	47.5	48.3	51.8
CIE whiteness	75.1	74.3	74.8	75.6	76.2
Yellowness	5.35	5.82	5.66	5.47	5.26
L*	95.2	94.8	95.1	95.2	95.3
a*	0.00	-0.03	-0.07	-0.06	-0.11
b*	2.84	2.93	2.81	2.79	2.77

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 15 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BBS with GCC and CS, 5 kg/t at 15% ash level*

Table 74: Properties of BBS pulp with GCC and amphoteric strength additive at 5 kg/t

GCC addition, %	Reference*	40	48	56	67
Retained ash, %	14.8	15.2	18.4	20.9	23.7
FPAR, %	51.8	53.2	56.6	58.2	59.1
CSF, ml	540	505	510	520	530
Streaming potential, mV	-220	-191	-180	-183	-170
Charge demand, µeq/l	10.8	6.3	5.0	4.3	4.0
Zeta potential, mV	-8.3	-4.7	-3.6	-2.4	-2.0
Conductivity, mS	0.419	0.425	0.428	0.43	0.438
Bulk, cc/g	1.33	1.34	1.34	1.32	1.31
Breaking length, m	3085	3072	2872	2692	2669
Burst index, kN/g	1.59	1.63	1.44	1.36	1.25
Tear index, mNm^2/g	4.98	5.00	4.82	4.62	4.46
Bending stiffness, mNm	0.137	0.140	0.134	0.122	0.117
Double fold, no.	7	6	6	5	4
ZD tensile strength, kPa	601	595	581	561	535
Air permeance, Gurley s	42.5	44.1	38.5	35.5	32.7
Bendtsen roughness, ml/min	85	100	97	84	84
Brightness, %ISO	84.4	84.7	85.0	85.7	86.5
Opacity, %ISO	85.1	85.3	86.9	87.2	88.2
Scattering coefficient, m^2/kg	44.9	45.6	46.9	48.3	53.4
CIE whiteness	75.1	76.6	77.4	77.9	79.6
Yellowness	5.35	4.81	4.71	4.64	4.35
L*	95.2	95.2	95.4	95.6	95.8
a*	0.00	-0.03	0.01	-0.01	0.00
b*	2.84	2.48	2.47	2.45	2.24

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 5 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BBS with GCC and CS, 5 kg/t at 15% ash level*

Table 75: Properties of BBS pulp with GCC and amphoteric strength additive at 10 kg/t

GCC addition, %	Reference*	40	48	56	67
Retained ash, %	14.8	15.5	18.8	21.1	23.9
FPAR, %	51.8	54.1	57.9	58.8	59.6
CSF, ml	540	505	515	520	535
Streaming potential, mV	-220	-175	-151	-141	-131
Charge demand, µeq/l	10.8	5.7	4.6	4.0	3.7
Zeta potential, mV	-8.3	-2.4	-1.4	0.5	1.6
Conductivity, mS	0.419	0.427	0.435	0.440	0.453
Bulk, cc/g	1.33	1.34	1.33	1.30	1.30
Breaking length, m	3085	3264	3002	2813	2651
Burst index, kN/g	1.59	1.73	1.51	1.51	1.40
Tear index, mNm^2/g	4.98	5.30	5.13	4.81	4.61
Bending stiffness, mNm	0.137	0.164	0.151	0.126	0.118
Double fold, no.	7	9	7	7	5
ZD tensile strength, kPa	601	626	601	580	557
Air permeance, Gurley s	42.5	44.6	38.2	36.6	32.8
Bendtsen roughness, ml/min	85	95	91	86	79
Brightness, %ISO	84.4	84.6	84.7	85.3	86.3
Opacity, %ISO	85.1	85.7	87.1	87.6	88.6
Scattering coefficient, m^2/kg	44.9	48.6	50.9	53.7	56.2
CIE whiteness	75.1	76.4	76.9	77.6	78.5
Yellowness	5.35	4.89	4.73	4.67	4.44
L*	95.2	95.2	95.3	95.4	95.6
a*	0.00	0.01	-0.01	0.00	0.00
b*	2.84	2.56	2.49	2.46	2.34

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 10 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BBS with GCC and CS, 5 kg/t at 15% ash level*

Table 76: Properties of BBS pulp with GCC and amphoteric strength additive at 15 kg/t

GCC addition, %	Reference*	40	48	56	67
Retained ash, %	14.8	15.7	19.1	21.4	24.1
FPAR, %	51.8	55.0	58.9	59.7	60.1
CSF, ml	540	510	515	525	535
Streaming potential, mV	-220	-121	-110	-105	-98
Charge demand, µeq/l	10.8	5.2	4.1	3.9	3.6
Zeta potential, mV	-8.3	1.1	1.5	1.8	2.1
Conductivity, mS	0.419	0.427	0.438	0.441	0.453
Bulk, cc/g	1.33	1.31	1.30	1.30	1.28
Breaking length, m	3085	3476	3208	2894	2852
Burst index, kN/g	1.59	1.86	1.75	1.63	1.54
Tear index, mNm^2/g	4.98	5.50	5.26	5.12	4.78
Bending stiffness, mNm	7	12	9	8	6
Double fold, no.	601	702	645	628	585
ZD tensile strength, kPa	0.137	0.181	0.168	0.135	0.128
Air permeance, Gurley s	42.5	46.0	41.5	37.2	34.1
Bendtsen roughness, ml/min	85	86	84	82	78
Brightness, %ISO	84.4	84.5	84.5	84.8	86.1
Opacity, %ISO	85.1	86.1	87.4	87.8	88.6
Scattering coefficient, m^2/kg	44.9	50.9	52.0	54.1	58.0
CIE whiteness	75.1	76.0	75.3	77.0	77.8
Yellowness	5.35	5.04	5.17	4.71	4.55
L*	95.2	95.1	95.2	95.2	95.4
a*	0.00	0.02	0.01	0.00	0.00
b*	2.84	2.64	2.71	2.47	2.39

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 15 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BBS with GCC and CS, 5 kg/t at 15% ash level*

Table 77: Properties of BBS pulp with PCC and cationic strength additive at 5 kg/t

PCC addition, %	Blank*	30	36	44	52
Retained ash, %		18.1	21.2	23.3	25.1
FPAR, %	-	82.9	83.5	81.4	78.6
CSF, ml	480	500	510	520	530
Streaming potential, mV	-231	-180	-172	-162	-157
Charge demand, µeq/l	12.6	8.2	7.8	7.3	7.1
Zeta potential, mV	-26.3	-11.2	-10.8	-10.4	-9.8
Conductivity, mS	0.386	0.437	0.433	0.435	0.440
Bulk, cc/g	1.36	1.46	1.47	1.49	1.52
Breaking length, m	3754	2508	2292	2039	1787
Burst index, kN/g	2.31	1.44	1.26	1.21	1.01
Tear index, mNm^2/g	5.53	4.42	4.31	4.13	3.43
Bending stiffness, mNm	0.197	0.148	0.144	0.129	0.119
Double fold, no.	12	7	6	5	4
ZD tensile strength, kPa	685	590	552	523	461
Air permeance, Gurley s	43.0	22.2	19.1	18.3	16.6
Bendtsen roughness, ml/min	66	99	95	90	82
Brightness, %ISO	82.6	84.4	85.1	85.4	85.8
Opacity, %ISO	77.6	85.1	86.0	86.8	88.1
Scattering coefficient, m^2/kg	32.1	48.0	50.7	54.8	60.9
CIE whiteness	71.4	75.3	76.3	76.7	77.1
Yellowness	5.89	5.40	5.22	5.12	4.77
L*	95.0	95.2	95.5	95.6	95.7
a*	-0.06	0.01	0.01	-0.02	-0.01
b*	3.12	2.82	2.75	2.67	2.47

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 5 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Blank: Unbeaten BBS pulp without addition of wet-end chemical*

Table 78: Properties of BBS pulp with PCC and cationic strength additive at 10 kg/t

PCC addition, %	Reference*	30	36	44	52
Retained ash, %	18.1	18.3	21.4	23.4	25.5
FPAR, %	82.9	83.9	84.2	82.1	79.7
CSF, ml	500	500	515	525	540
Streaming potential, mV	-180	-146	-135	-125	-115
Charge demand, µeq/l	8.2	7.2	6.5	6.3	5.8
Zeta potential, mV	-11.2	-9.2	-7.8	-6.9	-6.8
Conductivity, mS	0.437	0.442	0.448	0.452	0.458
Bulk, cc/g	1.46	1.48	1.49	1.50	1.51
Breaking length, m	2508	2518	2295	2092	1878
Burst index, kN/g	1.44	1.54	1.34	1.24	1.11
Tear index, mNm^2/g	4.42	4.55	4.34	4.19	3.58
Bending stiffness, mNm	0.148	0.191	0.170	0.149	0.131
Double fold, no.	7	8	7	5	5
ZD tensile strength, kPa	590	639	577	552	522
Air permeance, Gurley s	22.2	22.5	21.8	18.0	15.2
Bendtsen roughness, ml/min	99	96	94	90	85
Brightness, %ISO	84.4	84.0	84.4	85.0	85.6
Opacity, %ISO	85.1	85.4	86.6	87.0	88.0
Scattering coefficient, m^2/kg	48.0	49.2	51.0	55.4	59.1
CIE whiteness	75.3	75.0	76.1	76.6	76.9
Yellowness	5.40	5.44	5.25	5.19	5.08
L*	95.2	95.1	95.3	95.6	95.8
a*	0.01	0.06	0.04	-0.08	-0.08
b*	2.82	2.77	2.69	2.57	2.47

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 10 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: BBS with PCC and CS, 5 kg/t at 18% ash level*

Table 79: Properties of BBS pulp with PCC and cationic strength additive at 15 kg/t

PCC addition, %	Reference*	30	36	44	52
Retained ash, %	18.1	18.5	21.5	23.7	25.7
FPAR, %	82.9	84.5	84.9	82.8	80.4
CSF, ml	500	505	525	535	545
Streaming potential, mV	-180	-131	-128	-115	-98
Charge demand, µeq/l	8.2	6.4	5.8	5.1	4.3
Zeta potential, mV	-11.2	-7.3	-6.5	-5.8	-5.1
Conductivity, mS	0.437	0.446	0.451	0.455	0.458
Bulk, cc/g	1.46	1.48	1.49	1.49	1.52
Breaking length, m	2508	2738	2604	2349	1959
Burst index, kN/g	1.44	1.60	1.54	1.45	1.31
Tear index, mNm^2/g	4.42	4.71	4.35	4.26	3.93
Bending stiffness, mNm	0.148	0.204	0.175	0.146	0.138
Double fold, no.	7	10	8	7	6
ZD tensile strength, kPa	590	666	653	617	588
Air permeance, Gurley s	22.2	25.1	23.1	22.0	17.8
Bendtsen roughness, ml/min	99	94	73	89	87
Brightness, %ISO	84.4	84.0	84.6	85.0	85.3
Opacity, %ISO	85.1	85.3	86.1	86.9	88.1
Scattering coefficient, m^2/kg	48.0	49.2	50.3	53.6	57.1
CIE whiteness	75.3	75.0	76.3	76.0	76.7
Yellowness	5.40	5.41	5.21	5.15	5.08
L*	95.2	95.2	95.2	95.1	95.5
a*	0.01	-0.05	0.00	0.04	0.01
b*	2.82	2.76	2.71	2.63	2.46

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 15 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: BBS with PCC and CS, 5 kg/t at 18% ash level*

Table 80: Properties of BBS pulp with PCC and amphoteric strength additive at 5 kg/t

PCC addition, %	Reference*	30	36	44	52
Retained ash, %	18.1	18.3	21.3	23.3	25.3
FPAR, %	82.9	83.8	83.9	81.5	79.2
CSF, ml	500	500	515	525	535
Streaming potential, mV	-180	-202	-198	-192	-182
Charge demand, µeq/l	8.2	6.5	5.8	4.6	3.8
Zeta potential, mV	-11.2	-8.5	-7.9	-9.6	-7.3
Conductivity, mS	0.437	0.442	0.445	0.447	0.449
Bulk, cc/g	1.46	1.47	1.48	1.49	1.50
Breaking length, m	2508	2667	2283	2169	1939
Burst index, kN/g	1.44	1.44	1.25	1.13	1.08
Tear index, mNm^2/g	5.56	4.44	4.18	3.97	3.61
Bending stiffness, mNm	0.148	0.133	0.129	0.126	0.120
Double fold, no.	7	7	5	4	4
ZD tensile strength, kPa	590	620	599	567	532
Air permeance, Gurley s	22.2	19.6	18.7	15.4	13.9
Bendtsen roughness, ml/min	99	110	96	95	91
Brightness, %ISO	84.4	84.3	85.0	85.6	86.0
Opacity, %ISO	85.1	86.3	86.7	88.0	89.0
Scattering coefficient, m^2/kg	48.0	49.9	52.5	56.8	61.7
CIE whiteness	75.3	75.6	77.0	77.8	78.3
Yellowness	5.40	5.18	5.01	4.79	4.73
L*	95.2	95.1	95.5	95.7	95.8
a*	0.01	0.03	-0.02	-0.03	-0.04
b*	2.82	2.71	2.65	2.54	2.51

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 5 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: BBS with PCC and CS, 5 kg/t at 18% ash level*

Table 81: Properties of BBS pulp with PCC and amphoteric strength additive at 10 kg/t

PCC addition, %	Reference*	30	36	44	52
Retained ash, %	18.1	18.5	21.4	23.6	25.7
FPAR, %	82.9	84.6	84.6	82.5	80.3
CSF, ml	500	505	520	530	540
Streaming potential, mV	-180	-179	-152	-131	-125
Charge demand, µeq/l	8.2	5.2	4.7	4.2	3.5
Zeta potential, mV	-11.2	-5.0	-3.5	-2.9	-2.0
Conductivity, mS	0.437	0.454	0.461	0.469	0.46
Bulk, cc/g	1.46	1.46	1.47	1.47	1.49
Breaking length, m	2508	2764	2436	2229	2041
Burst index, kN/g	1.44	1.56	1.34	1.28	1.14
Tear index, mNm^2/g	4.44	4.55	4.28	4.17	3.53
Bending stiffness, mNm	0.148	0.153	0.148	0.129	0.128
Double fold, no.	7	8	6	6	5
ZD tensile strength, kPa	590	668	623	607	590
Air permeance, Gurley s	22.2	19.6	16.8	16.0	14.2
Bendtsen roughness, ml/min	99	106	101	93	90
Brightness, %ISO	84.4	84.1	84.7	85.4	85.6
Opacity, %ISO	85.1	86.2	86.9	87.6	89.2
Scattering coefficient, m^2/kg	48.0	50.1	52.3	55.4	60.9
CIE whiteness	75.3	75.3	76.8	77.9	77.6
Yellowness	5.40	5.20	4.94	4.77	4.78
L*	95.2	95.2	95.4	95.7	95.5
a*	0.01	0.04	0.02	0.03	0.01
b*	2.82	2.72	2.59	2.50	2.51

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 10 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: BBS with PCC and CS, 5 kg/t at 18% ash level*

Table 82: Properties of BBS pulp with PCC and amphoteric strength additive at 15 kg/t

PCC addition, %	Reference*	30	36	44	52
Retained ash, %	18.1	18.7	21.7	23.8	25.9
FPAR, %	82.9	85.6	85.5	83.2	80.9
CSF, ml	500	510	525	530	545
Streaming potential, mV	-180	-161	-143	-125	-108
Charge demand, µeq/l	8.2	4.1	3.6	3.2	2.8
Zeta potential, mV	-11.2	-1.4	-2.4	-2.6	-1.6
Conductivity, mS	0.437	0.465	0.469	0.454	0.461
Bulk, cc/g	1.46	1.47	1.46	1.48	1.49
Breaking length, m	2508	3172	2873	2550	2313
Burst index, kN/g	1.44	1.58	1.47	1.36	1.33
Tear index, mNm^2/g	4.44	4.74	4.40	4.26	3.88
Bending stiffness, mNm	0.148	0.170	0.150	0.146	0.138
Double fold, no.	7	9	8	6	6
ZD tensile strength, kPa	590	681	669	637	612
Air permeance, Gurley s	22.2	20.5	20.4	18.2	17.1
Bendtsen roughness, ml/min	99	99	98	88	86
Brightness, %ISO	84.4	84.0	84.5	85.2	85.7
Opacity, %ISO	85.1	86.4	87.0	87.8	89.3
Scattering coefficient, m^2/kg	48.0	49.6	52.1	55.3	59.3
CIE whiteness	75.3	75.6	77.0	77.1	77.7
Yellowness	5.40	5.25	4.75	4.88	4.74
L*	95.2	95.2	95.4	95.7	95.5
a*	0.01	-0.01	-0.01	0.00	0.00
b*	2.82	2.76	2.50	2.57	2.50

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 15 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: BBS with PCC and CS, 5 kg/t at 18% ash level*

Table 83: Properties of BBS pulp with PCC and polymeric strength additive at 6 kg/t

PCC addition, %	Reference*	24	30	36	44
Retained ash, %	18.1	12.8	15.8	18.0	20.4
FPAR, %	82.9	66.3	68.6	68.0	66.8
CSF, ml	500	420	425	425	430
Streaming potential, mV	-180	-166	-126	-115	-100
Charge demand, µeq/l	8.2	12.3	8.3	7.2	6.7
Zeta potential, mV	-11.2	-11.4	-10.8	-10.4	-9.8
Conductivity, mS	0.437	0.435	0.437	0.440	0.439
Bulk, cc/g	1.46	1.40	1.43	1.43	1.44
Breaking length, m	2735	3142	3057	2832	2722
Burst index, kN/g	1.50	1.65	1.50	1.45	1.33
Tear index, mNm^2/g	4.54	4.71	4.50	4.22	3.96
Bending stiffness, mNm	0.148	0.154	0.145	0.136	0.130
Double fold, no.	7	7	6	5	5
ZD tensile strength, kPa	590	628	610	588	550
Air permeance, Gurley s	22.2	31.6	25.1	24.4	21.7
Bendtsen roughness, ml/min	99	97	95	88	81
Brightness, %ISO	84.4	83.9	84.2	84.7	85.2
Opacity, %ISO	86.0	85.5	86.2	86.8	87.7
Scattering coefficient, m^2/kg	46.9	46.2	49.6	49.5	55.0
CIE whiteness	75.3	74.5	75.7	76.0	76.7
Yellowness	5.40	5.25	5.05	5.06	4.77
L*	95.2	94.8	95.1	95.2	95.2
a*	0.01	-0.01	-0.01	-0.01	-0.02
b*	2.82	2.75	2.69	2.66	2.55

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + PS, 6 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: BBS with PCC and CS, 5 kg/t at 18% ash level*

Table 84: Properties of BBS pulp with PCC and polymeric strength additive at 8 kg/t

PCC addition, %	Reference*	24	30	36	44
Retained ash, %	18.1	12.6	15.6	17.7	20.1
FPAR, %	82.9	64.7	67.8	66.8	65.8
CSF, ml	500	420	425	420	440
Streaming potential, mV	-180	-168	-130	-118	-105
Charge demand, µeq/l	8.2	12.4	8.6	7.6	7.2
Zeta potential, mV	-11.2	-12.1	-11.5	-10.7	-9.1
Conductivity, mS	0.437	0.450	0.452	0.445	0.470
Bulk, cc/g	1.46	1.40	1.42	1.43	1.43
Breaking length, m	2735	3280	3111	2952	2832
Burst index, kN/g	1.50	1.68	1.62	1.59	1.49
Tear index, mNm^2/g	4.54	4.92	4.72	4.43	4.06
Bending stiffness, mNm	0.148	0.172	0.161	0.146	0.135
Double fold, no.	7	8	7	6	5
ZD tensile strength, kPa	590	640	625	600	578
Air permeance, Gurley s	22.2	32.7	30.5	27.0	24.1
Bendtsen roughness, ml/min	99	86	78	73	70
Brightness, %ISO	84.4	83.7	84.1	84.7	85.0
Opacity, %ISO	86.0	85.5	86.1	86.5	87.6
Scattering coefficient, m^2/kg	46.9	45.7	49.3	51.5	53.0
CIE whiteness	75.3	74.5	75.7	75.6	76.7
Yellowness	5.40	5.26	5.05	5.09	4.79
L*	95.2	94.8	95.0	95.1	95.2
a*	0.01	-0.01	-0.02	-0.01	-0.02
b*	2.82	2.75	2.66	2.68	2.52

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + PS, 8 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: BBS with PCC and CS, 5 kg/t at 18% ash level*

Table 85: Properties of BBS pulp with PCC and polymeric strength additive at 10 kg/t

PCC addition, %	Reference*	24	30	36	44
Retained ash, %	18.1	12.3	15.4	17.3	19.8
FPAR, %	82.9	63.3	66.9	65.4	64.8
CSF, ml	500	415	430	435	440
Streaming potential, mV	-180	-170	-132	-120	-104
Charge demand, µeq/l	8.2	12.8	9	8.2	7.8
Zeta potential, mV	-11.2	-14	-11.7	-10.8	-9.5
Conductivity, mS	0.437	0.442	0.444	0.442	0.441
Bulk, cc/g	1.46	1.38	1.40	1.42	1.42
Breaking length, m	2735	3360	3240	3162	2911
Burst index, kN/g	1.50	1.72	1.69	1.62	1.63
Tear index, mNm^2/g	4.54	5.04	4.83	4.67	4.27
Bending stiffness, mNm	0.148	0.178	0.169	0.159	0.147
Double fold, no.	7	9	7	6	6
ZD tensile strength, kPa	590	658	632	612	591
Air permeance, Gurley s	22.2	33.8	32.8	28.6	25.6
Bendtsen roughness, ml/min	99	81	76	74	73
Brightness, %ISO	84.4	83.5	84.0	84.5	85.0
Opacity, %ISO	86.0	85.3	85.9	86.3	86.6
Scattering coefficient, m^2/kg	46.9	45.8	49.1	51.4	51.4
CIE whiteness	75.3	74.3	75.6	76.5	76.5
Yellowness	5.40	5.39	5.21	5.17	4.88
L*	95.2	94.8	95.0	95.1	95.4
a*	0.01	0.03	0.01	0.01	0.00
b*	2.82	2.77	2.73	2.67	2.51

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + PS, 10 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: BBS with PCC and CS, 5 kg/t at 18% ash level*

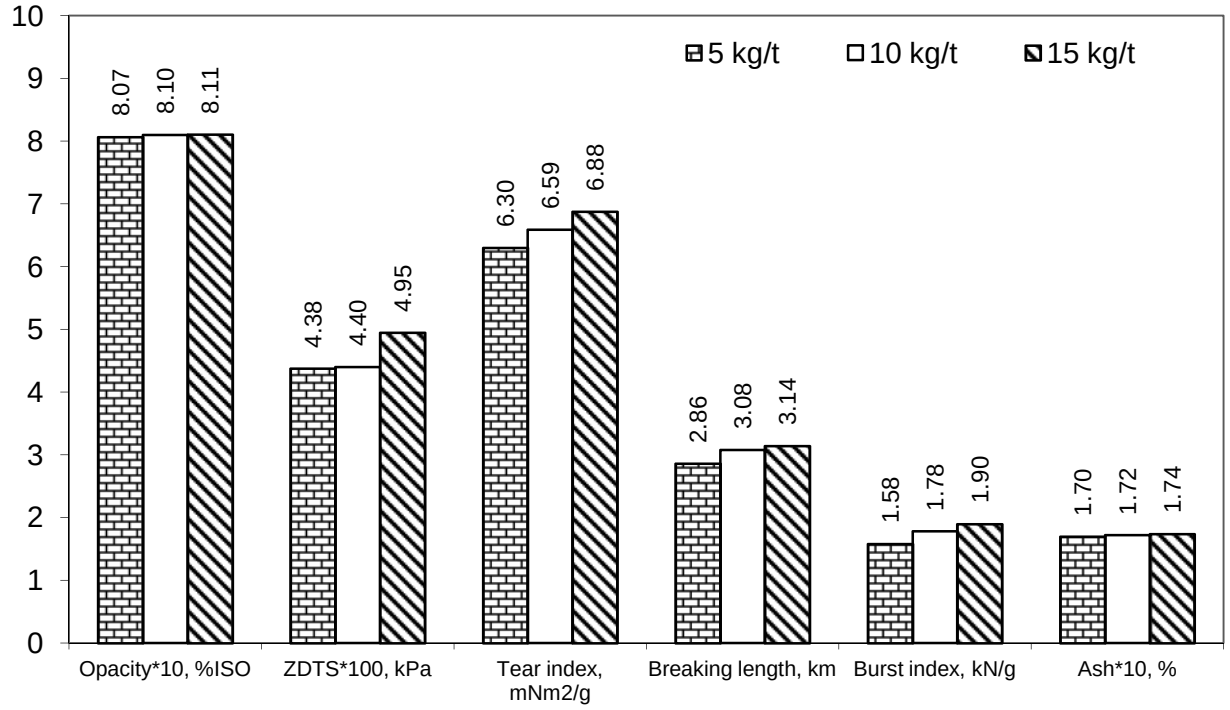

Figure 69: Effect of CS on properties of BBS pulp at 280 kg/t addition of talc

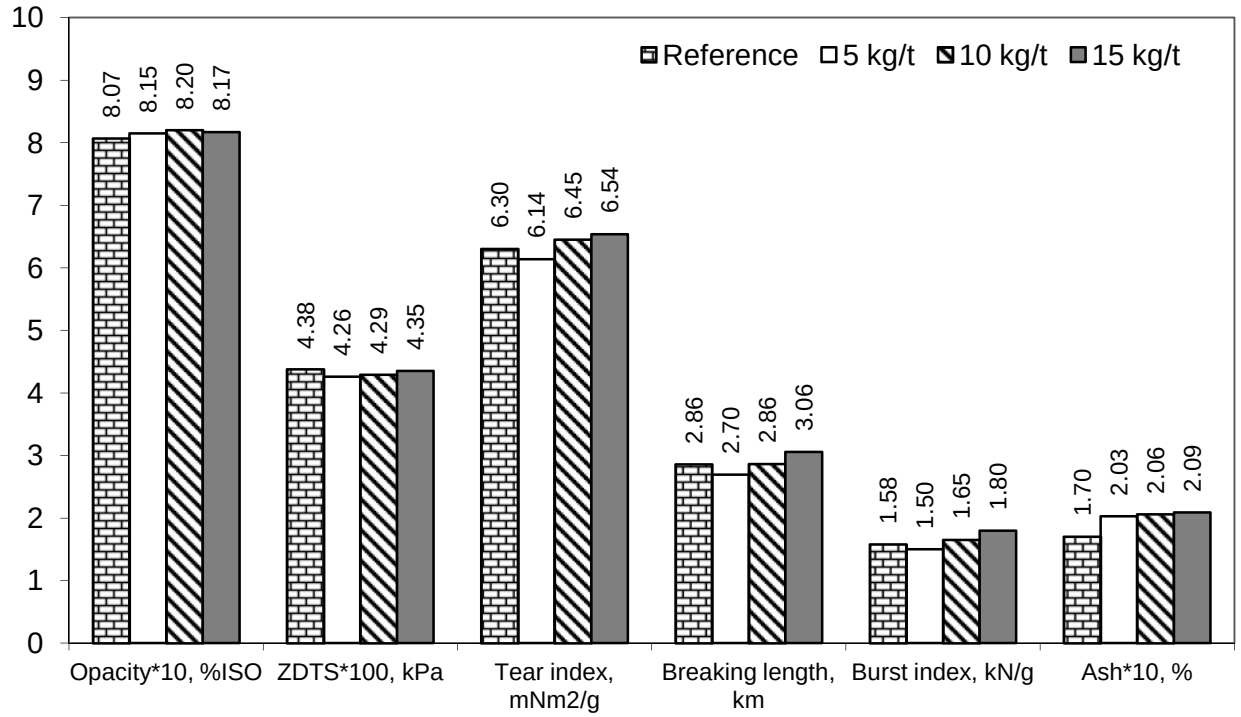

Figure 70: Effect of CS on properties of BBS pulp at 340 kg/t addition of talc

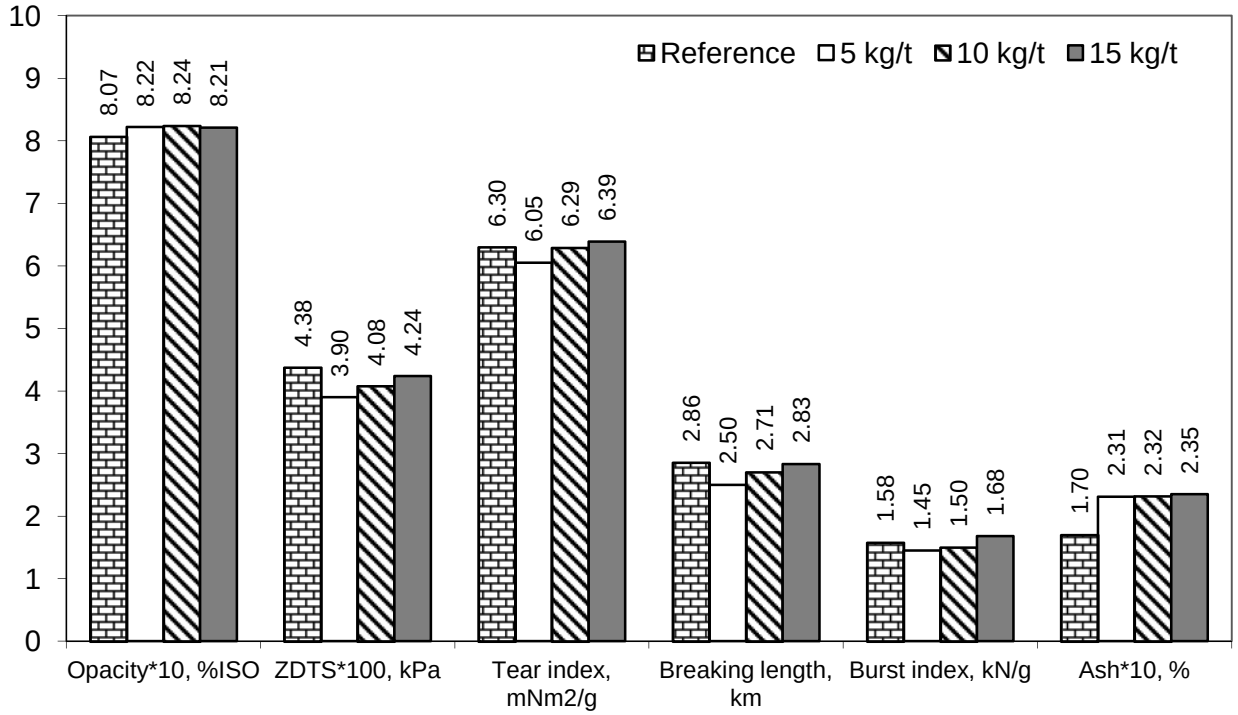

Figure 71: Effect of CS on properties of BBS pulp at 400 kg/t addition of talc

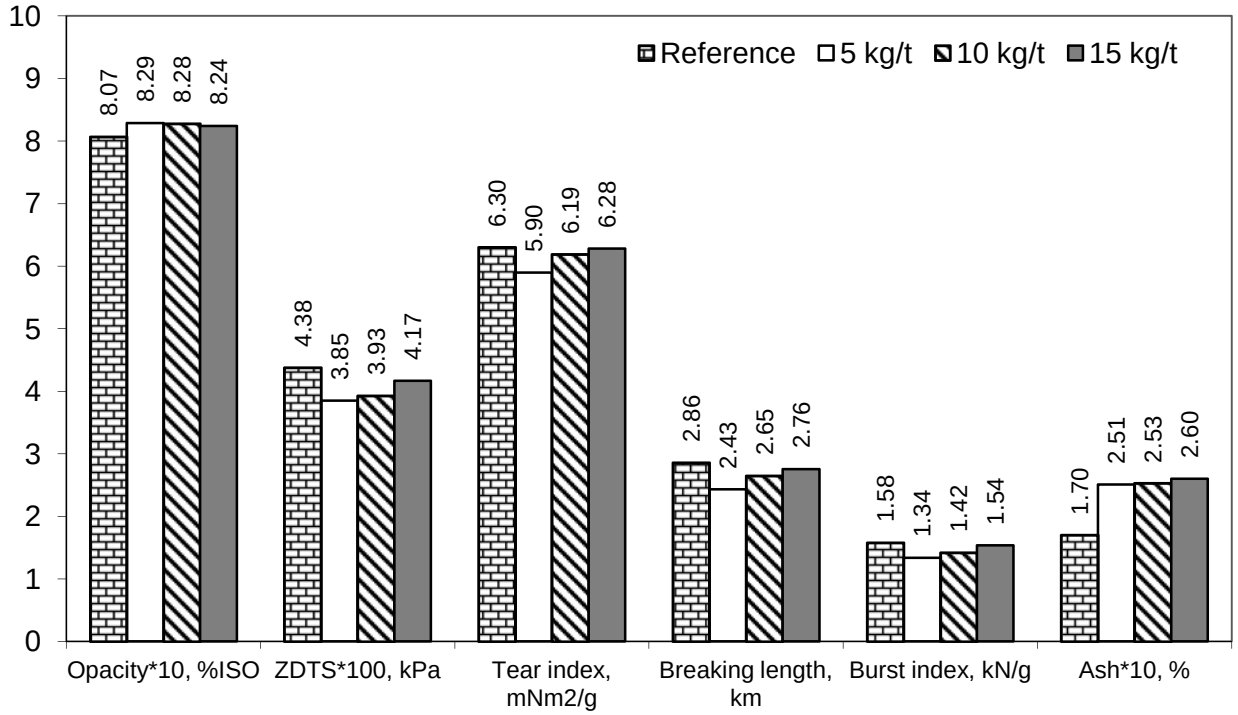

Figure 72: Effect of CS on properties of BBS pulp at 470 kg/t addition of talc

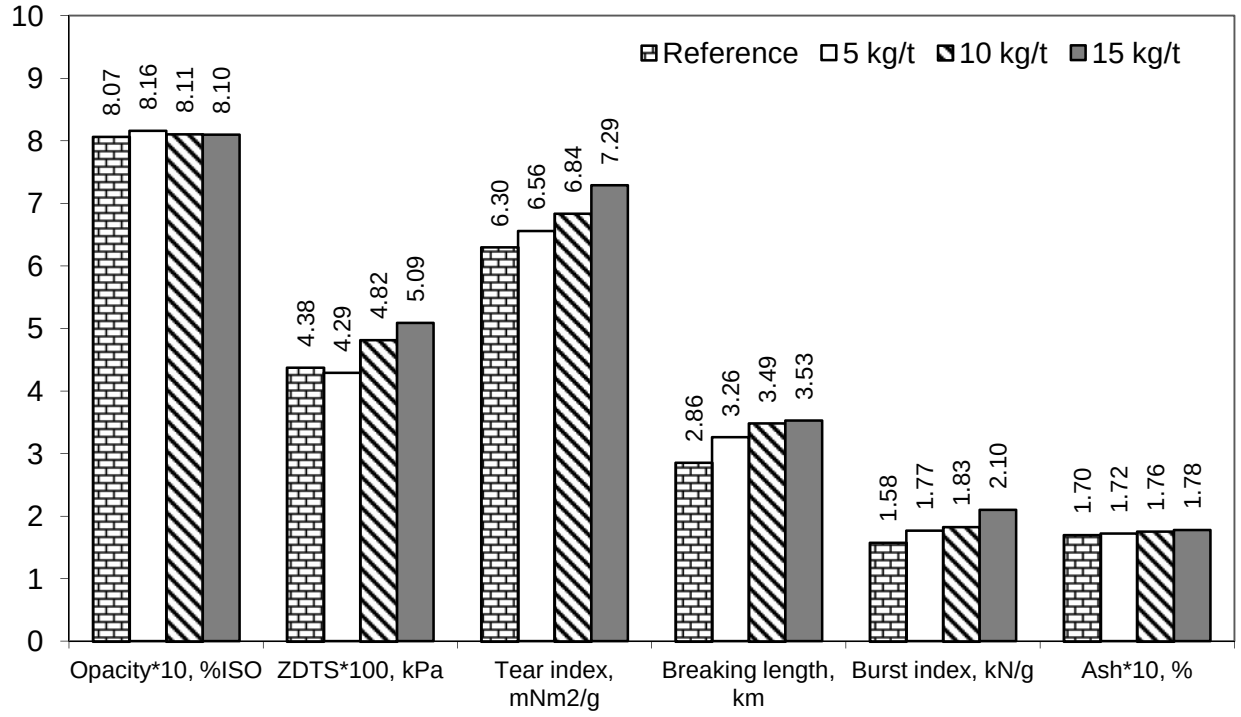

Figure 73: Effect of AS on properties of BBS pulp at 280 kg/t addition of talc

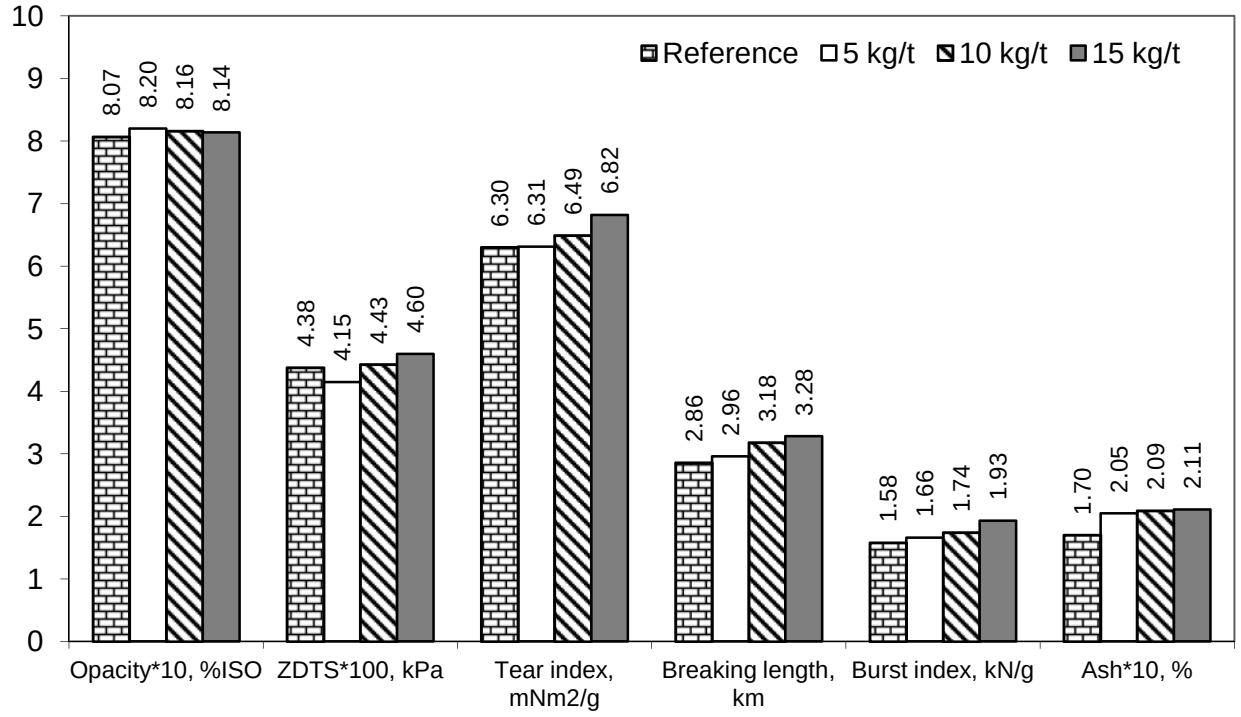

Figure 74: Effect of AS on properties of BBS pulp at 340 kg/t addition of talc

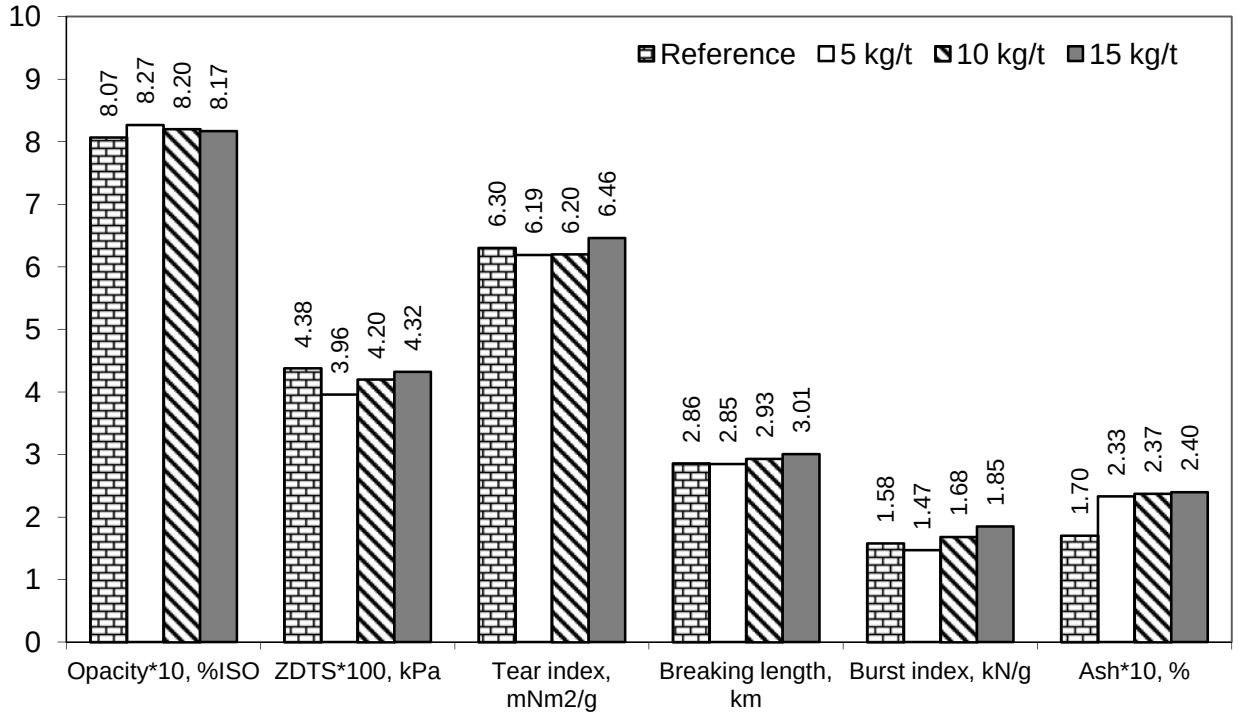

Figure 75: Effect of AS on properties of BBS pulp at 400 kg/t addition of talc

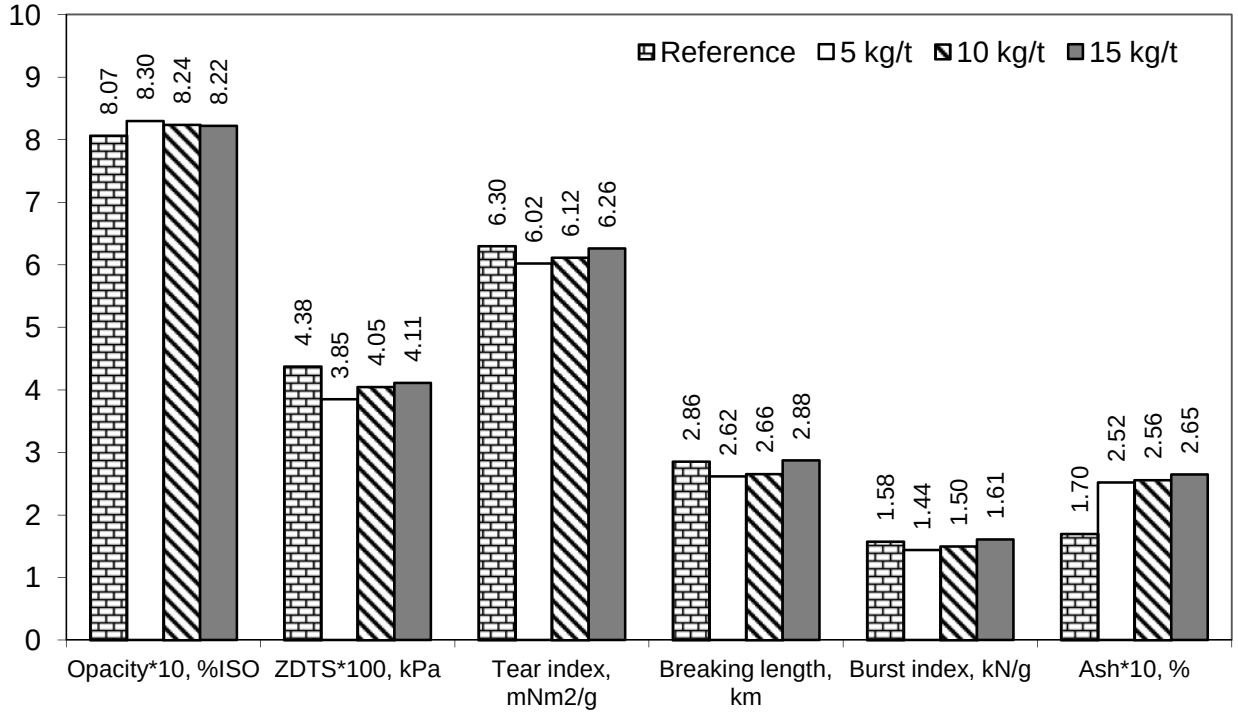

Figure 76: Effect of AS on properties of BBS pulp at 470 kg/t addition of talc

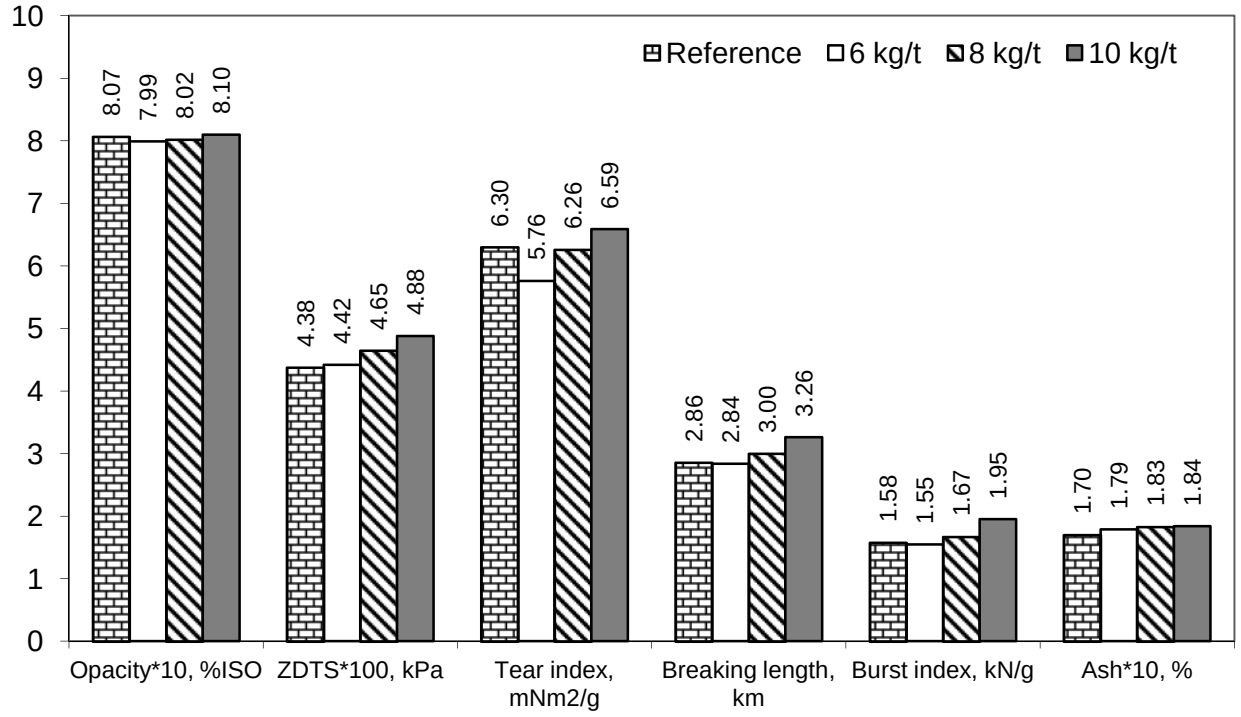

Figure 77: Effect of PS on properties of BBS pulp at 280 kg/t addition of talc

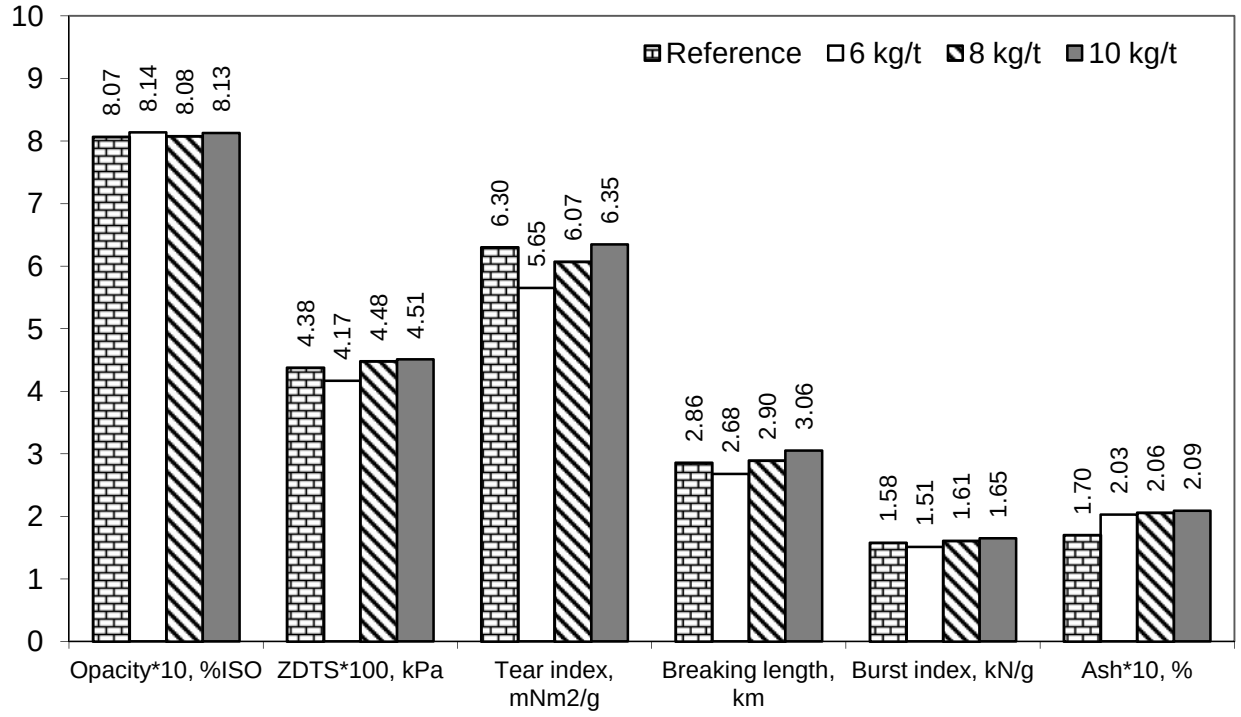

Figure 78: Effect of PS on properties of BBS pulp at 340 kg/t addition of talc

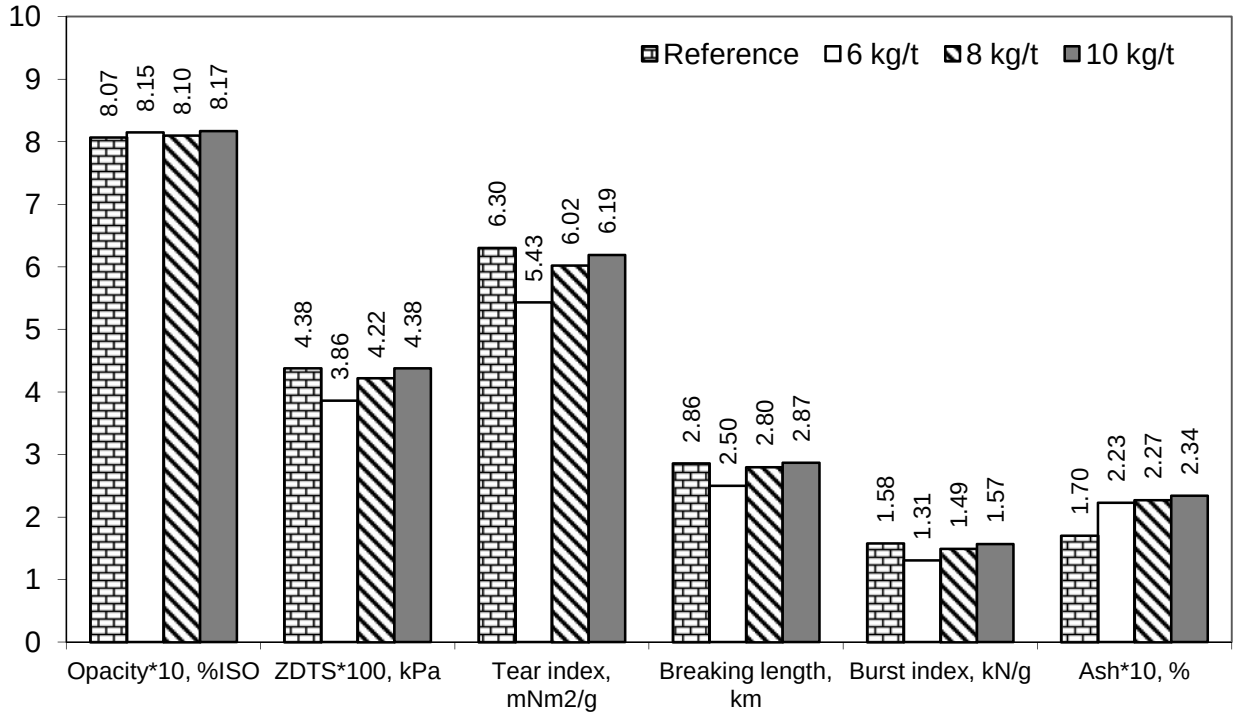

Figure 79: Effect of PS on properties of BBS pulp at 400 kg/t addition of talc

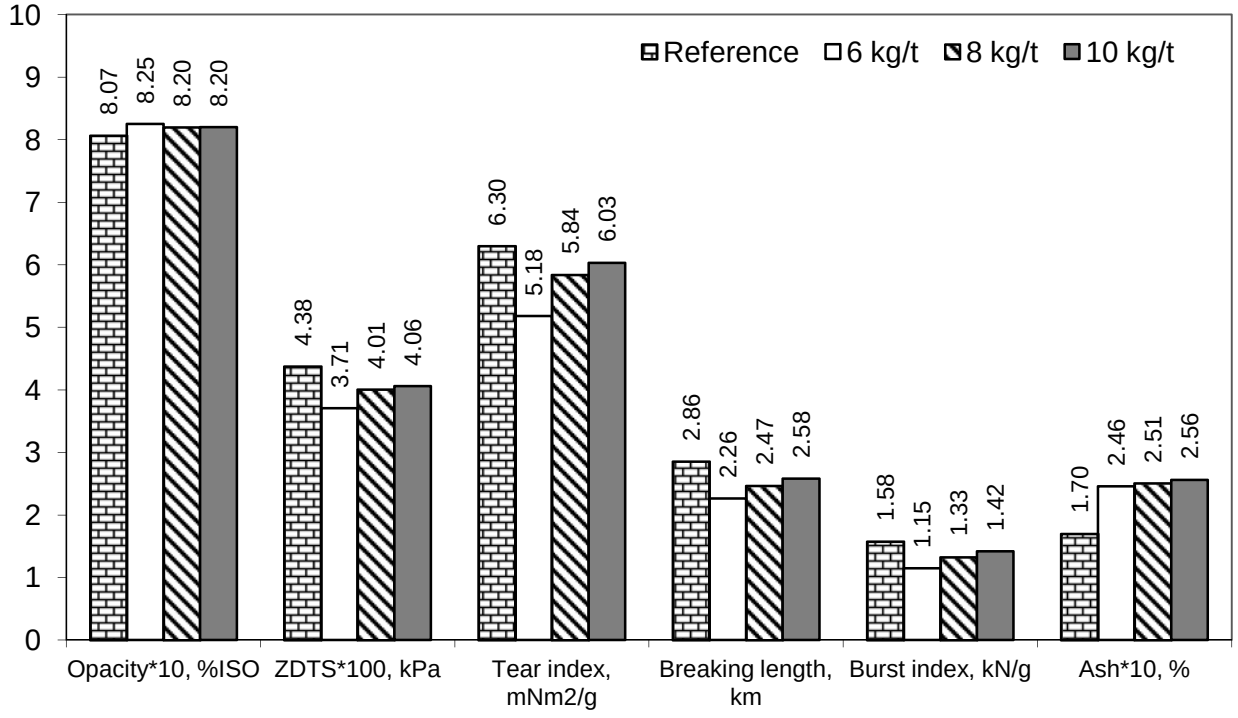

Figure 80: Effect of PS on properties of BBS pulp at 470 kg/t addition of talc

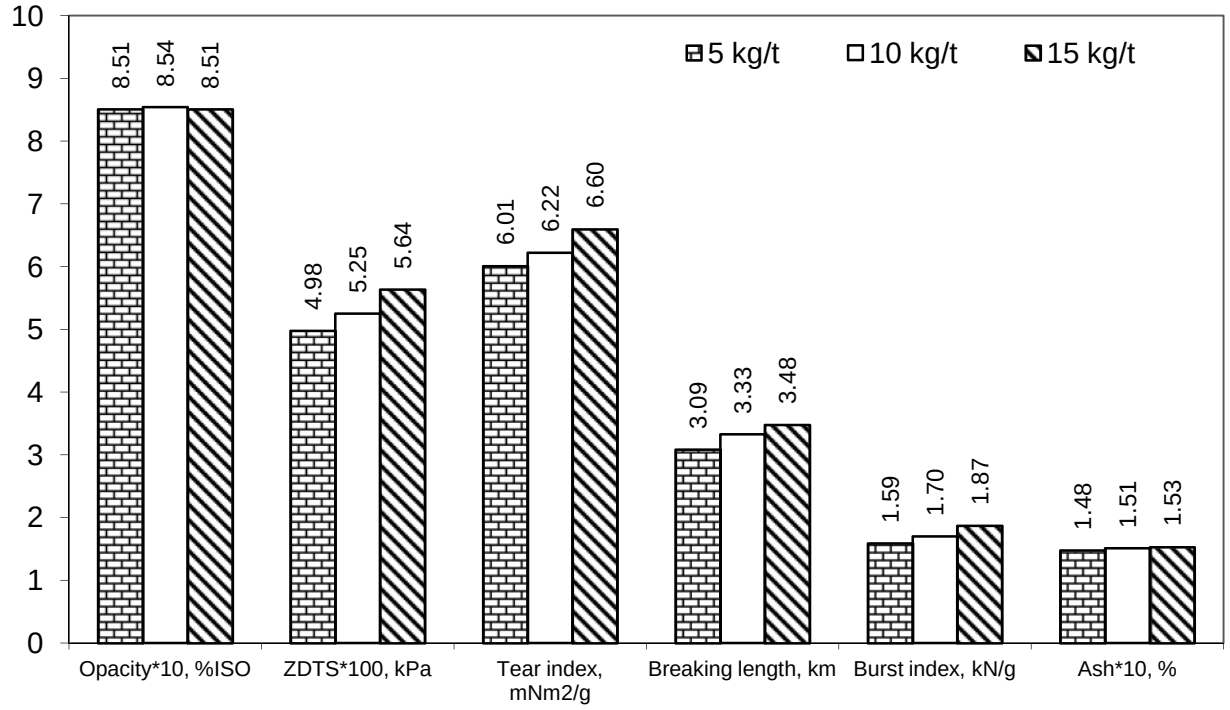

Figure 81: Effect of CS on properties of BBS pulp at 400 kg/t addition of GCC

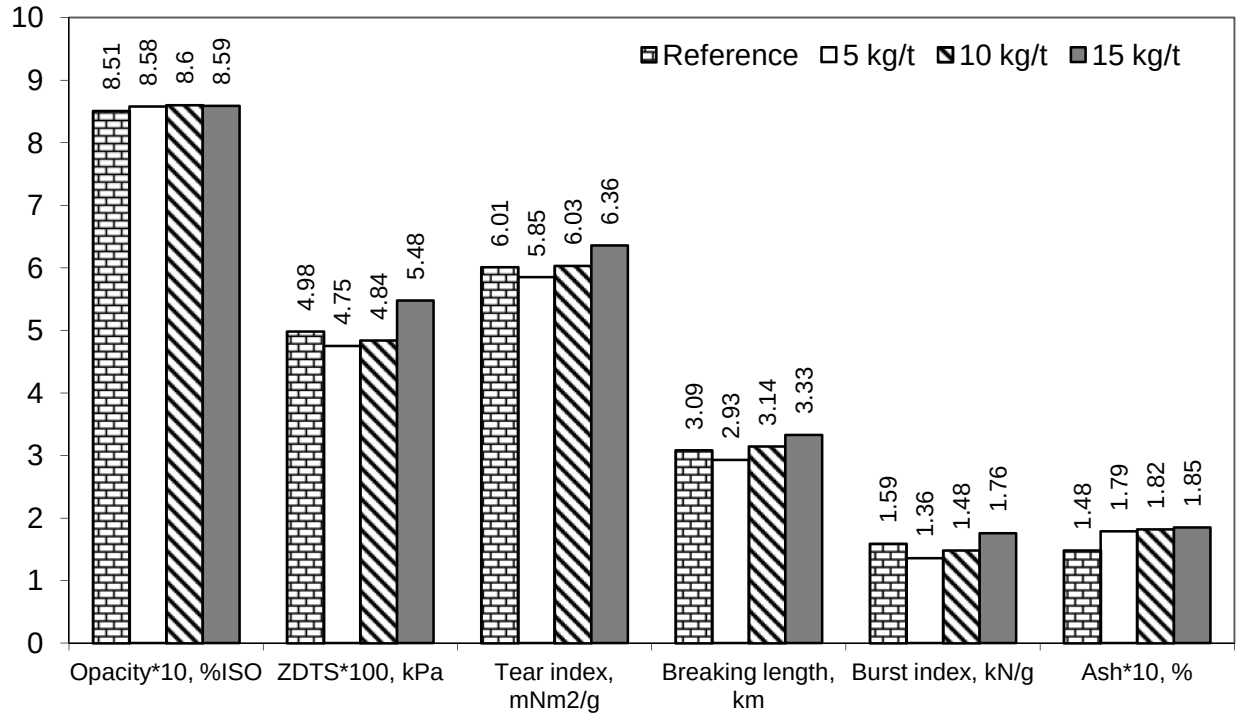

Figure 82: Effect of CS on properties of BBS pulp at 480 kg/t addition of GCC

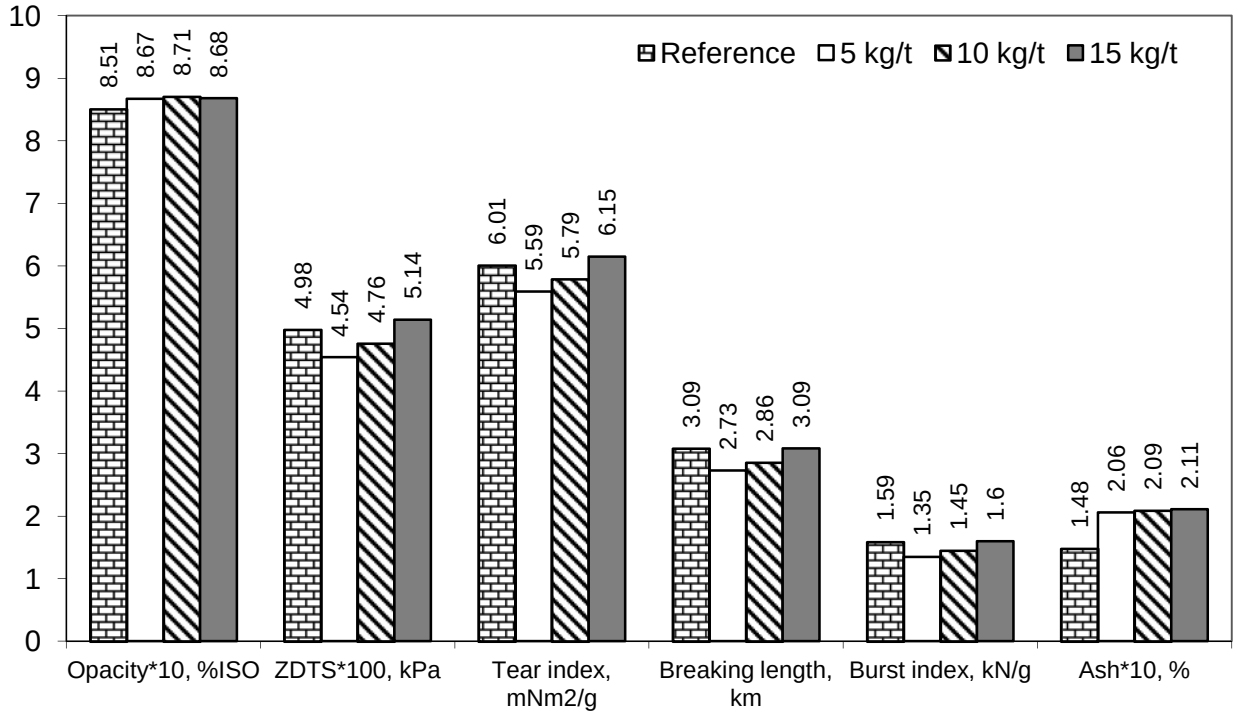

Figure 83: Effect of CS on properties of BBS pulp at 560 kg/t addition of GCC

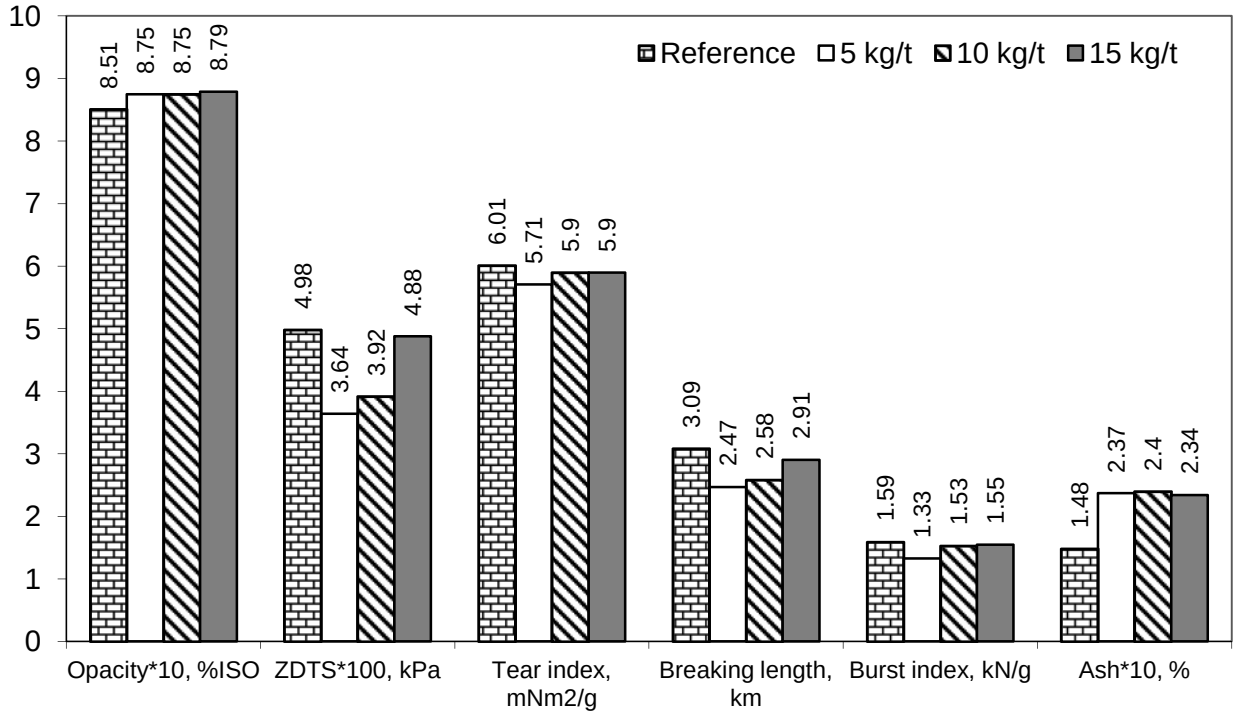

Figure 84: Effect of CS on properties of BBS pulp at 670 kg/t addition of GCC

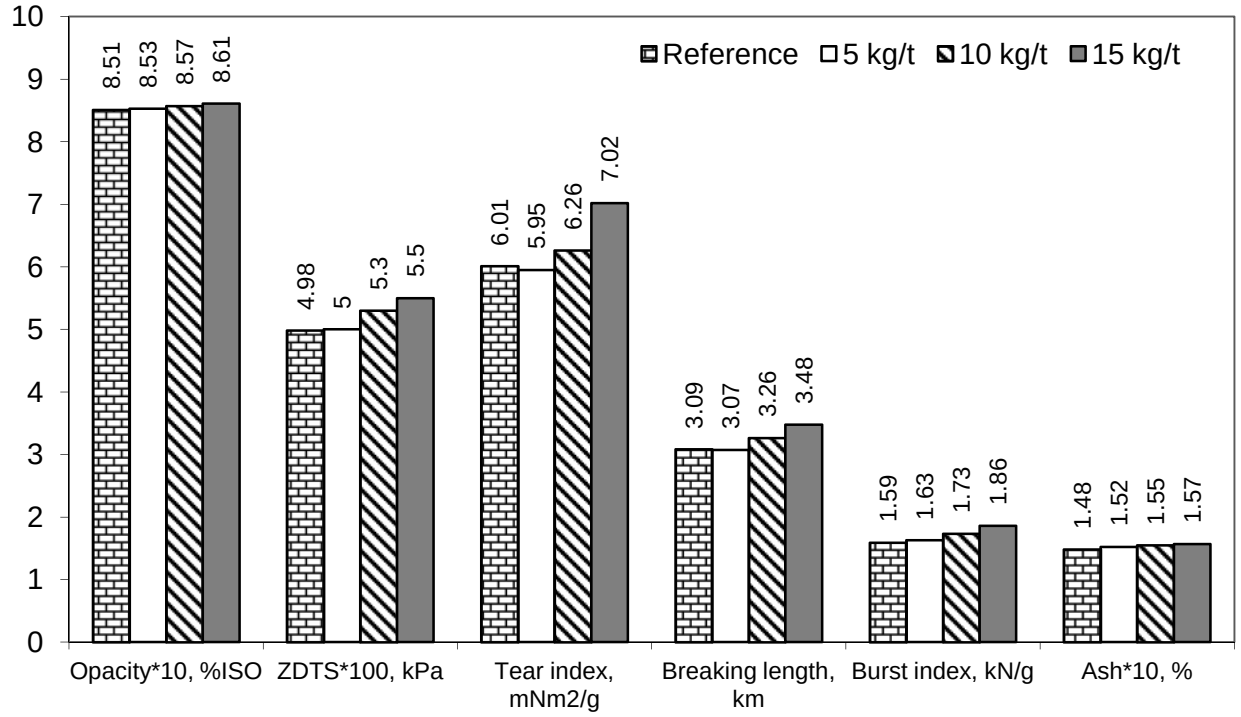

Figure 85: Effect of AS on properties of BBS pulp at 400 kg/t addition of GCC

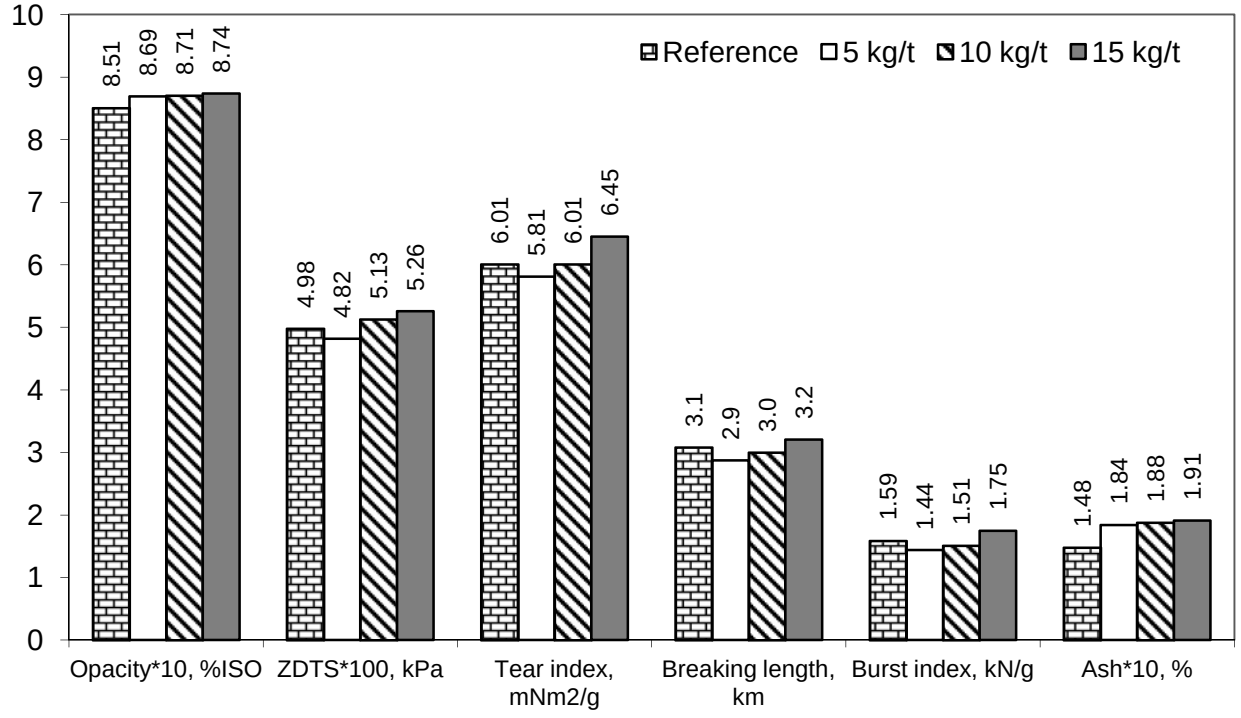

Figure 86: Effect of AS on properties of BBS pulp at 480 kg/t addition of GCC

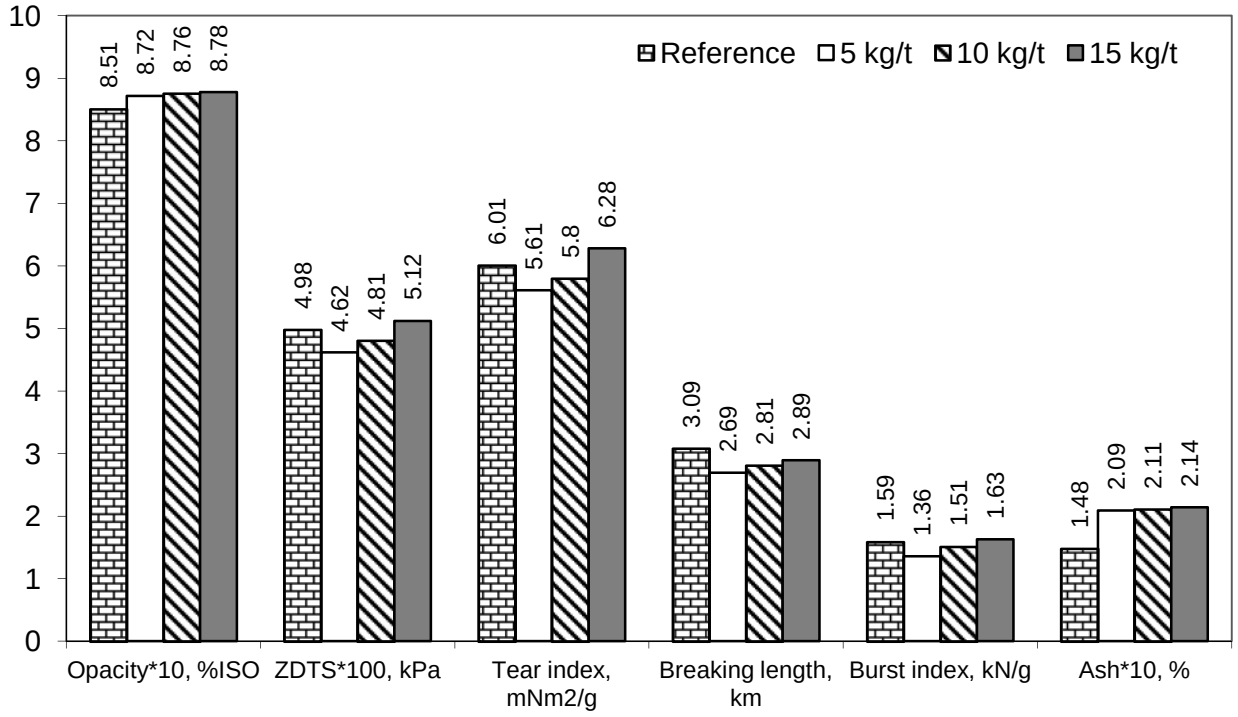

Figure 87: Effect of CS on properties of BBS pulp at 560 kg/t addition of GCC

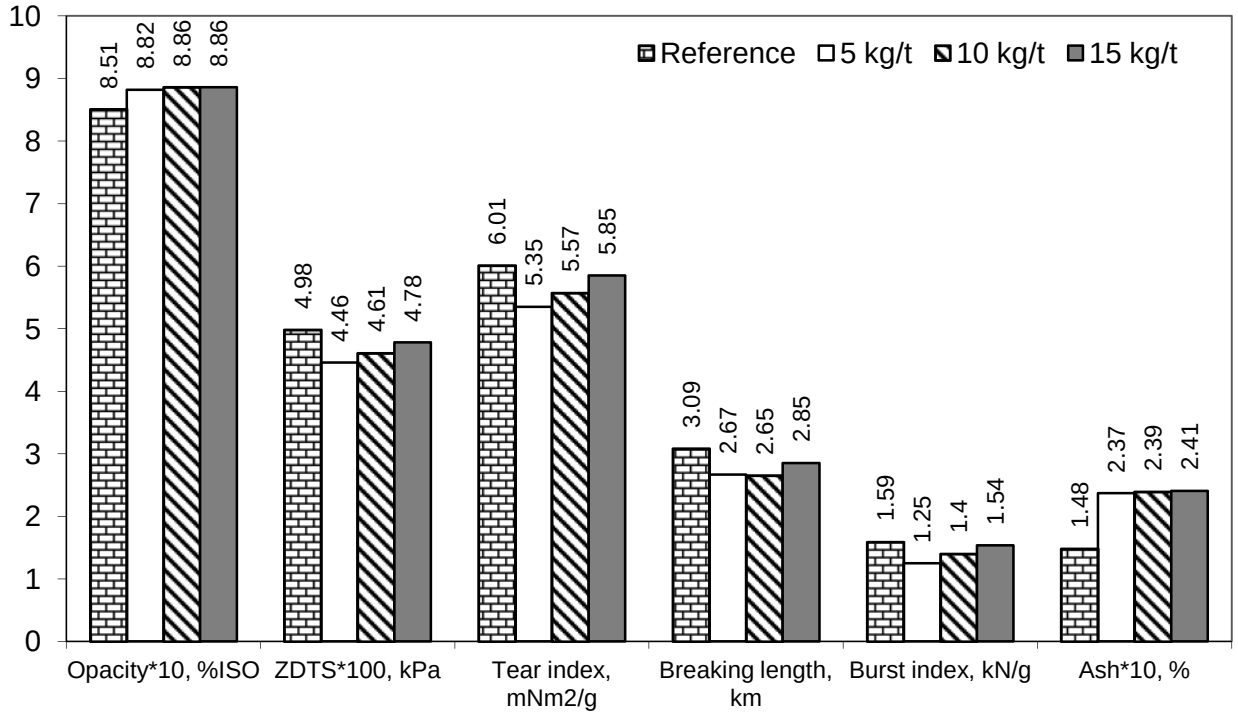

Figure 88: Effect of CS on properties of BBS pulp at 670 kg/t addition of GCC

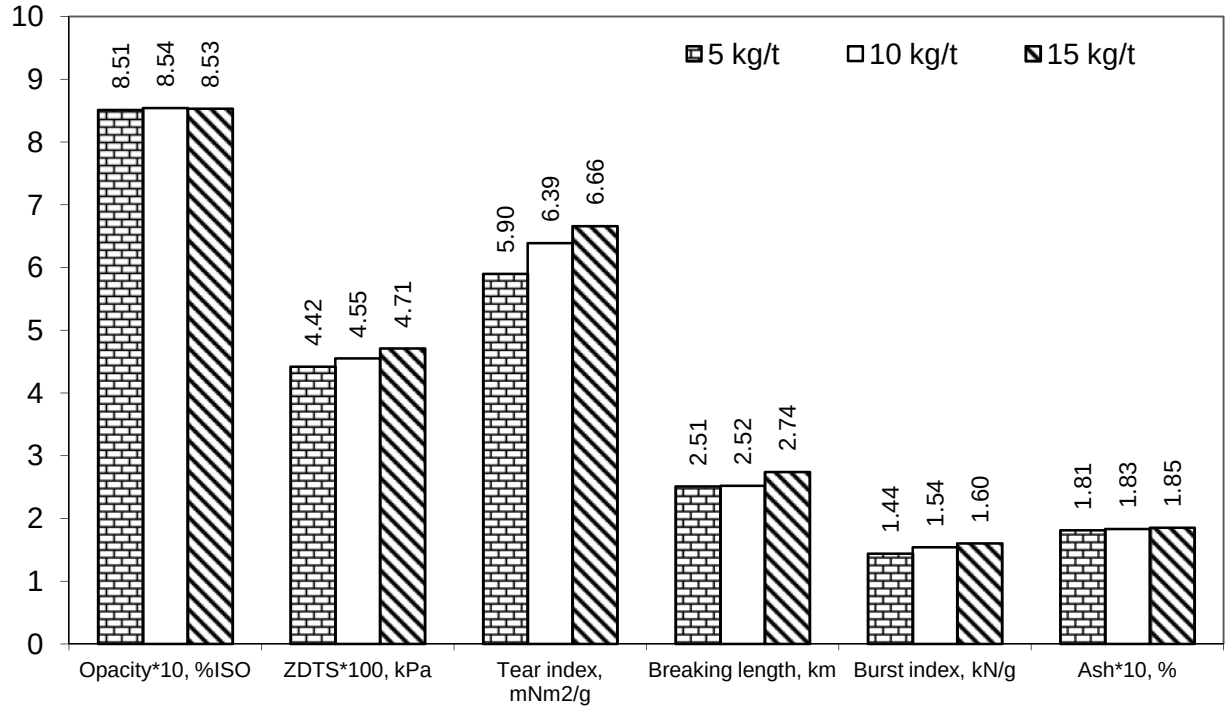

Figure 89: Effect of CS on properties of BBS pulp at 300 kg/t addition of PCC

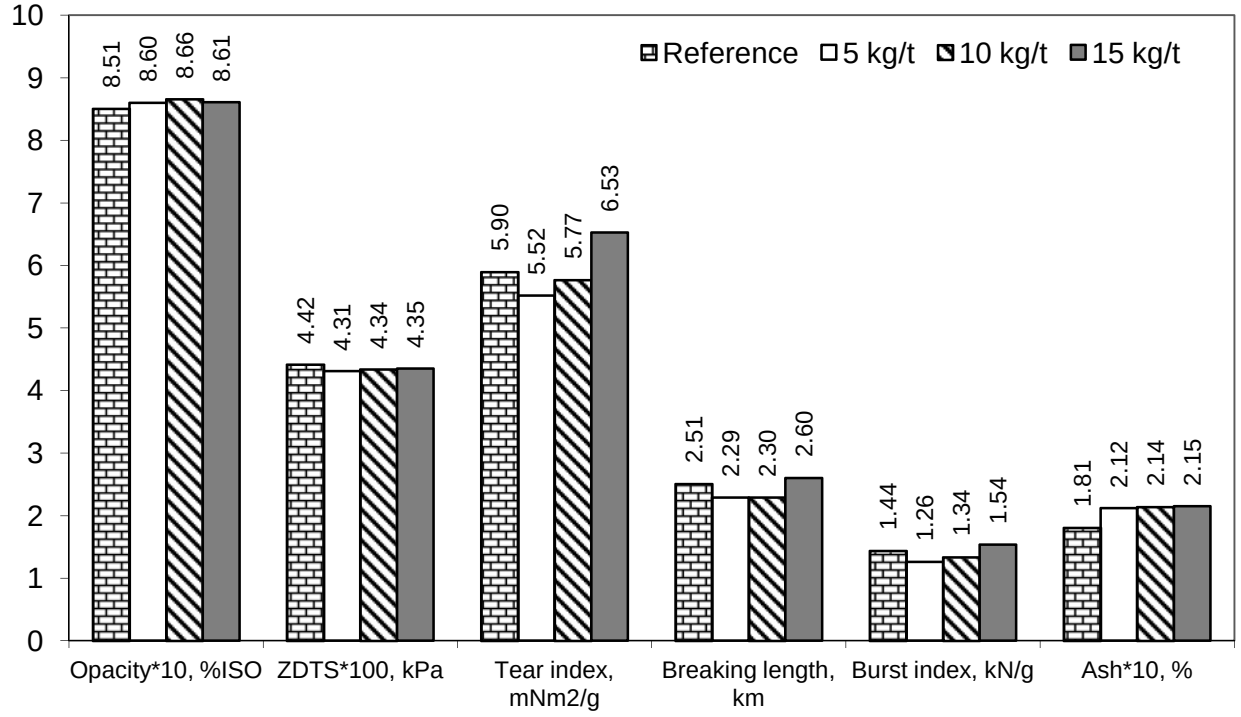

Figure 90: Effect of CS on properties of BBS pulp at 360 kg/t addition of PCC

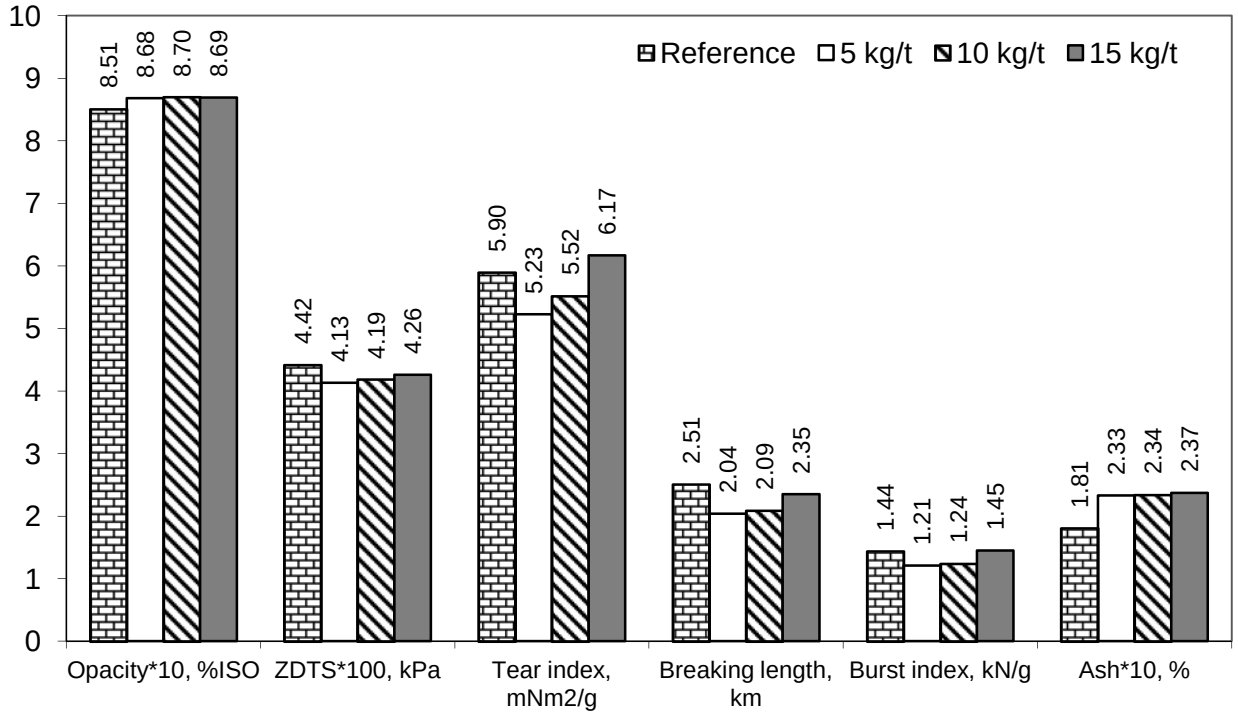

Figure 91: Effect of CS on properties of BBS pulp at 440 kg/t addition of PCC

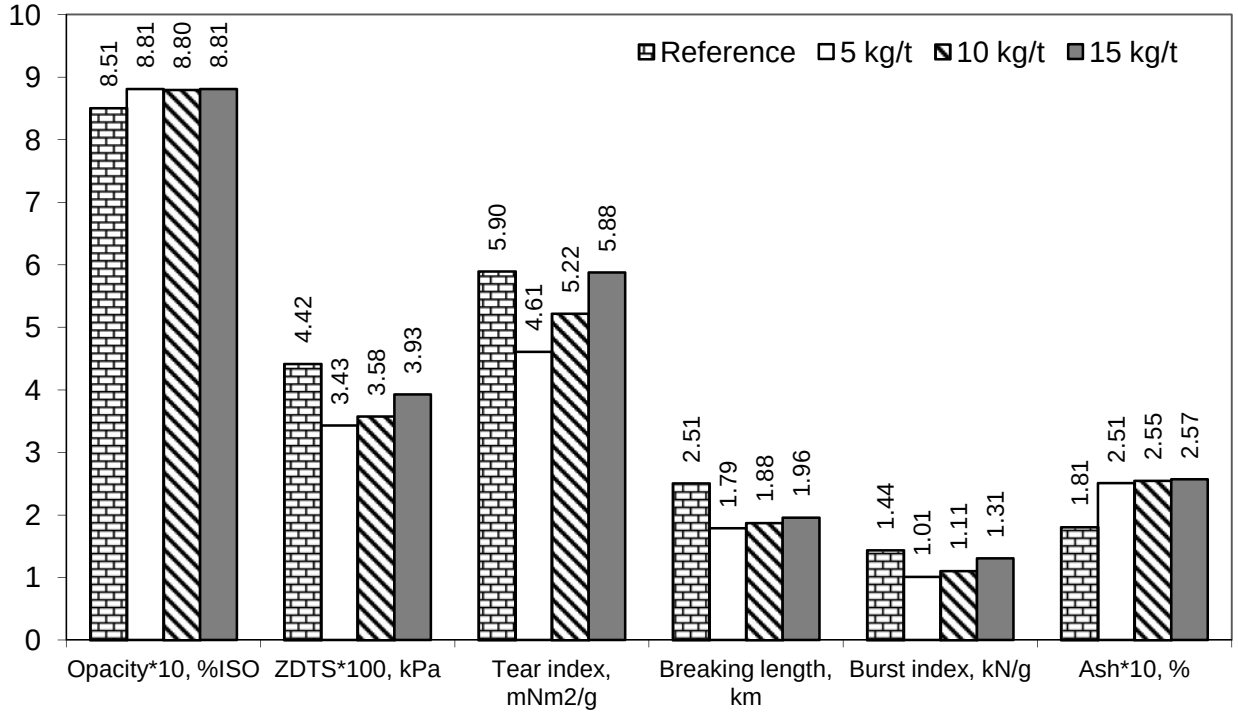

Figure 92: Effect of CS on properties of BBS pulp at 520 kg/t addition of PCC

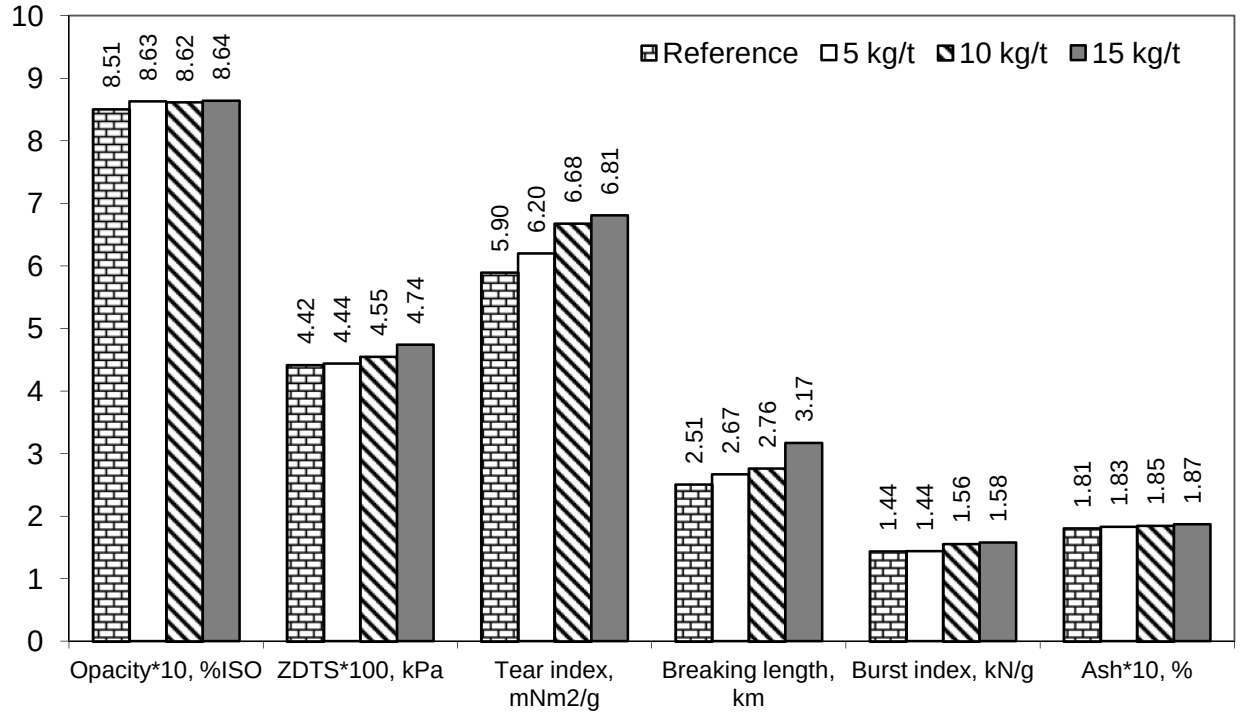

Figure 93: Effect of AS on properties of BBS pulp at 300 kg/t addition of PCC

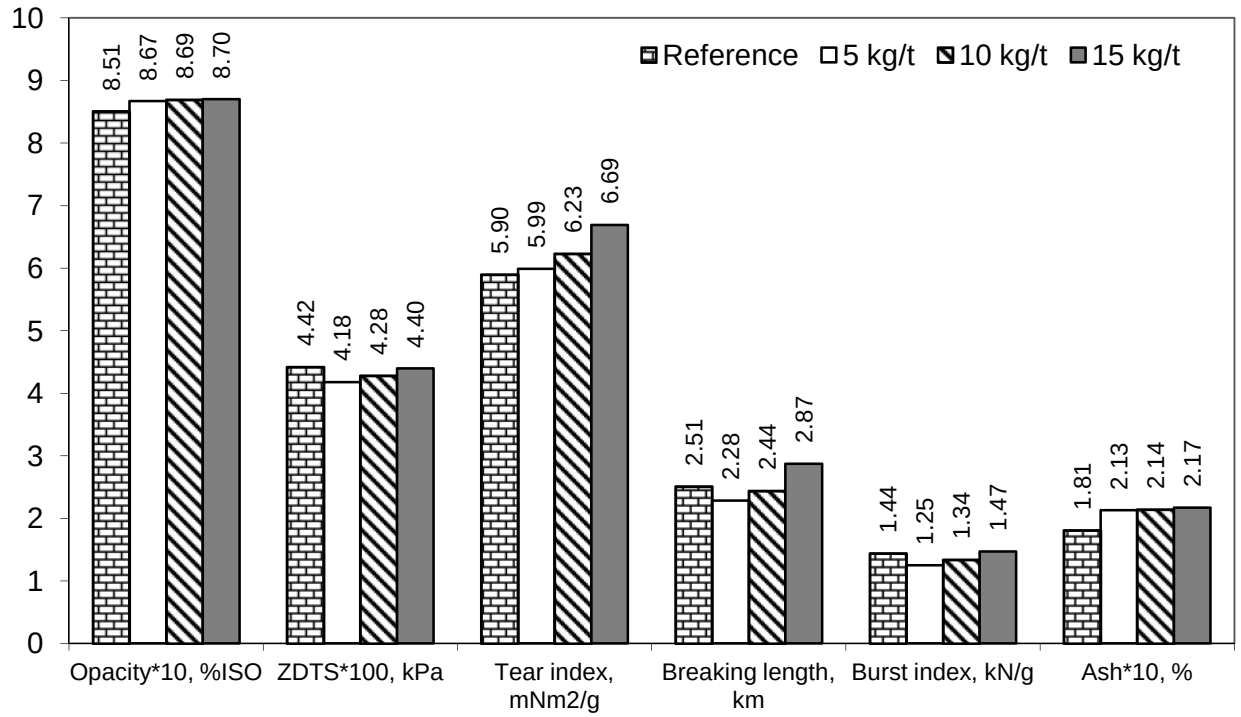

Figure 94: Effect of AS on properties of BBS pulp at 360 kg/t addition of PCC

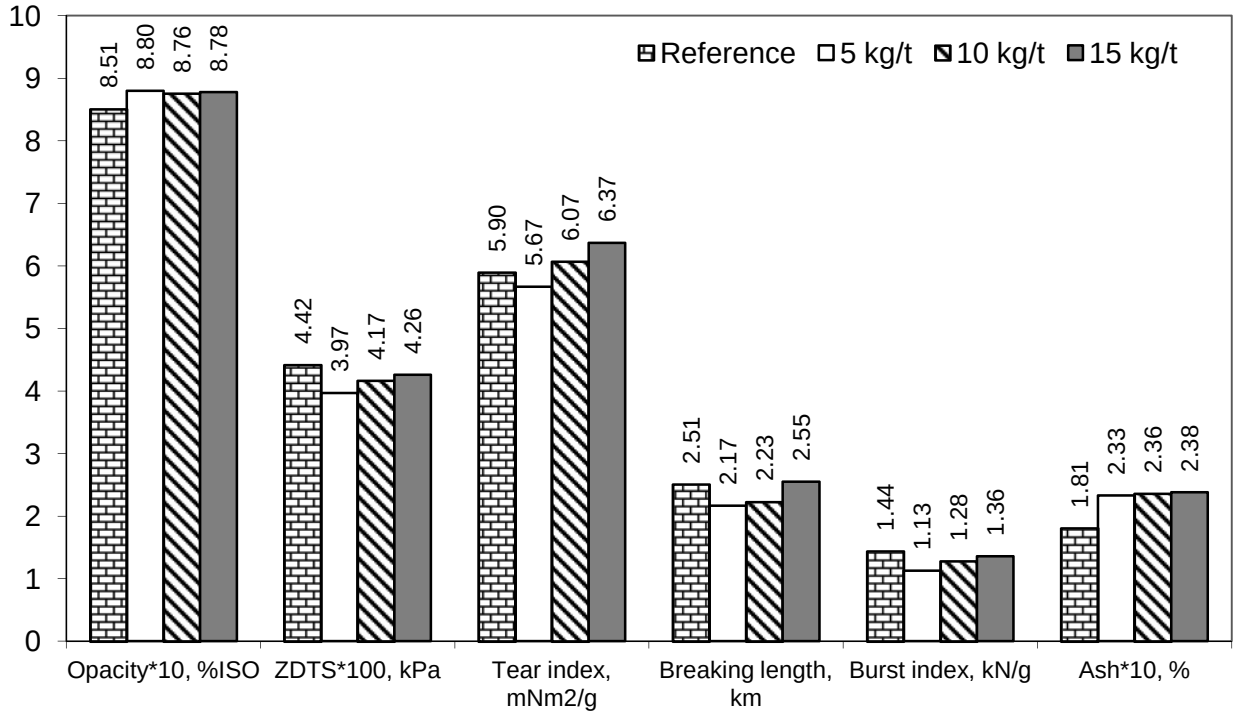

Figure 95: Effect of AS on properties of BBS pulp at 440 kg/t addition of PCC

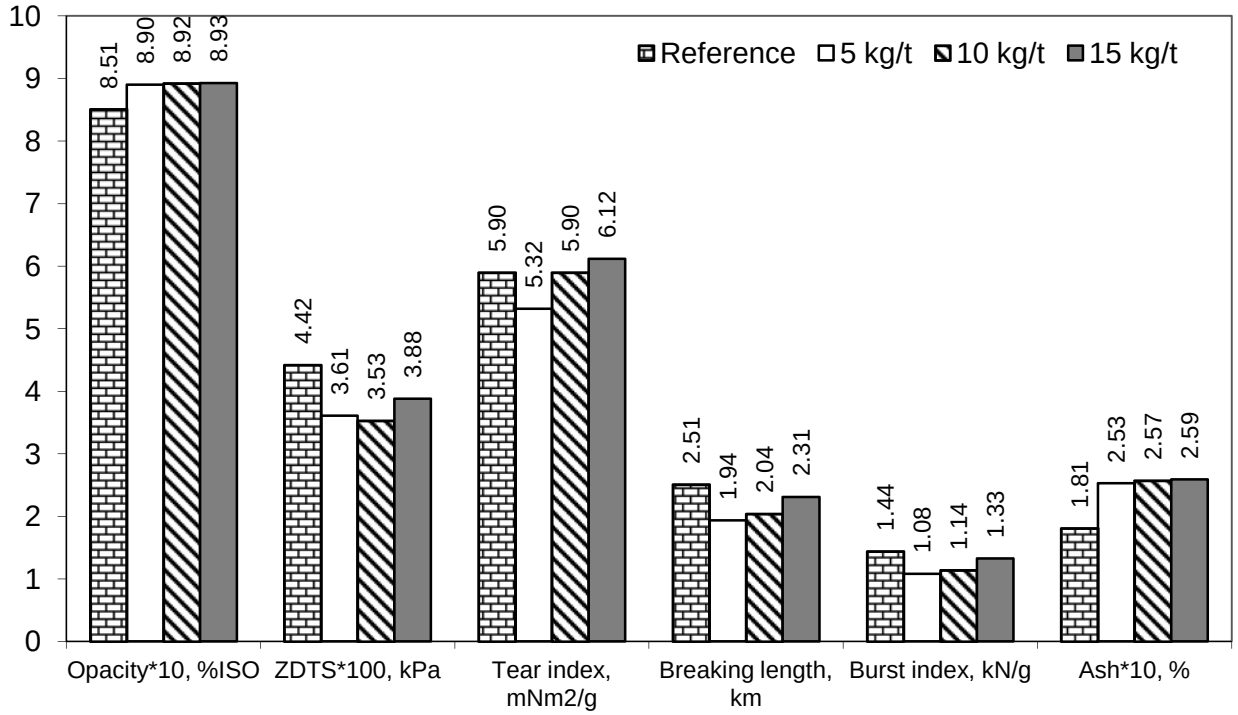

Figure 96: Effect of AS on properties of BBS pulp at 520 kg/t addition of PCC

CHAPTER – 4

Bleached Wheat Straw (BWS) Pulp

RESULTS & DISCUSSION

4.1. Effect of cationic strength additive and talc filler on paper properties

It has been previously discussed that the filler loading in paper decreases the paper strength and increases the optical properties. The similar results were obtained from the bleached wheat straw (BWS) pulp. The results of effect of increasing filler content in paper at different dose levels of cationic strength additive (CS) are shown Table 86-88. The FPAR was comparatively higher in case of BWS pulp than that with hardwood and BBS pulps may be due to its higher fines content which in turn helped the retention of filler in paper.

4.1.1. At 190 kg/t of talc

At 190 kg/t dose of talc, the ash content in sheets was 15.2-15.6% at all doses of CS. There was an increase in physical properties of paper with increase in CS dose. Tear index and opacity were almost comparable at all doses of CS (Figure 97).

4.1.2. At 250 kg/t of talc

At 250 kg/t addition of talc, the ash in sheets was 18.7-18.8% at all doses of CS. At 15 kg/t dose of CS, all strength properties were comparable with those of reference (15% ash with 5 kg/t dose of CS). From Figure 98 it was seen for talc as filler that ash in paper can be increased from 15 to 18.5% with 15 kg/t dose of CS without affecting the strength properties. The gain in opacity due to increased ash was 1.5%.

4.1.3. At 310 kg/t of talc

As shown in Figure 99, at 310 kg/t addition of talc, the ash in sheets was approximately 22% at all doses of CS. in case of BWS pulp and talc filler, the ash could be increased from 15 to 22% using 15 kg/t dose of CS with little drop in paper strength. The drop in tensile, burst, tear and ZDTS was around 11, 8, 6 and 4%, respectively. The gain in opacity due to increased ash was would be around 2.5%.

4.1.4. At 390 kg/t of talc

The increasing dosed of talc to 390 kg/t increased the ash in paper to ~25.5%. At this ahs level, all strength properties were quite lower than those of reference (Figure 100).

4.2. Effect of amphoteric strength additive and talc filler on paper properties

Similar to the results of CS, in case of amphoteric strength additive (AS) also, the strength properties were decreased with increasing ash in paper. Optical properties were increased at all doses of AS (Table 89-91).

4.2.1. At 190 kg/t of talc

At this talc addition level, the ash in paper was ~15.2-15.6; similar to that in case of CS. At this ash level, the strength properties of the sheets with both 5 kg/t dose of CS or AS were more or

less comparable; the latter gave slightly higher values. With increase in dose of AS, all strength properties were increased slightly (Figure 101).

4.2.2. At 250 kg/t of talc

At 250 kg/t addition of talc, the ash in sheets was ~18.6% with both 5 and 10 kg/t doses of AS. As shown in Figure 102, 5 to 10 kg/t dose of AS could be helpful to increase the ash in paper from 15.2 (reference) to 18.6% without adversely affecting the physical properties of paper. The comparable tear and breaking length and higher ZDTS and burst index were achieved with 10 kg/t dose of AS.

4.2.3. At 310 kg/t of talc

The ash in sheets increased to ~22.4% with increasing dose of talc to 310 kg/t. With increase in ash in paper from 15.2 (reference) to 22.4% (7.2 points), the drop in tear index, breaking length and burst index was 6.0, 8.2 and 4.9%, respectively. The ZDTS was comparable and the gain in opacity was around 4.7 points (Figure 103).

4.2.4. Effect of blending of long fibers with BWS pulp

The physical properties of paper made from BWS pulp were comparably lower than those of hardwood pulps. The lower tear index in case of BWS pulp might affect the machine runnability negatively. The papermakers blend some proportion of long fibers (hardwood, softwood) with BWS pulps to maintain few specific paper properties such as tear strength. We also did the same and blended hardwood and softwood with BWS pulp in the proportion of 15 and 5%, respectively. As expected, the improvement in all physical properties of paper was observed (Table 92-95). In order to reduce the future experiments by the papermakers, the weighted average results from the as such properties of long and short fibered pulps are also reported. The calculated values give good approximation of the blended results (Table 92). From this data the papermakers would be able to choose the required blending proportions based on their requirements.

4.3. Effect of cationic strength additive and GCC filler on paper properties

The different doses of CS were used at all four ash levels and the results are shown in Table 96-98. The zeta potential and charge demand of pulp slurries decreased with increase in dose of GCC. Due to cationic nature of CS, the zeta potential and charge demand also decreased with the increasing dose of CS. the FPAR of GCC filler was comparatively lower than that of talc filler. It was in the range of 70-75% with GCC against 85-88% in case of talc filler.

4.3.1. At 290 kg/t of GCC

At this addition level of GCC, the ash in paper was ~18% at all doses of CS. There was an increase in all the strength properties with increase in CS dose. Opacity was almost comparable at all CS dose (Figure 104).

4.3.2. At 350 kg/t of GCC

At 350 kg/t addition of GCC, the ash in paper was ~21% at all doses of CS. With 10 kg/t dose of CS, the strength properties were comparable to those of reference (18% ash with 5 kg/t dose of CS), with little increase in burst index as compared with reference (Figure 105). The ash in paper could be increased from 18 to 21% using 5 kg extra dose of CS without affecting the strength properties of paper and comparable opacity.

4.3.3. At 400 kg/t of GCC

At 400 kg/t addition of GCC, the ash in paper was ~23% at all doses of CS. The breaking length and burst index of paper with 15 kg/t dose of CS were comparable to those of reference. Little drop in ZDTS and tear index was observed; 3.4 and 5.9%, respectively (Figure 106).

The ash in paper could be increased from 18 to 21% and 23% with GCC as filler with the addition of 10 and 15 kg/t dose of CS, respectively.

4.4. Effect of amphoteric strength additive and GCC filler on paper properties

The effect of different doses of AS with increasing GCC filler level in paper on various process and paper properties is shown in Table 99-101.

4.4.1. At 290 kg/t of GCC

At this GCC addition level, the ash in paper was ~18.9-19.5% at all doses of CS; slightly higher than that with CS. The 5 kg/t dose of AS gave comparable paper properties to 5 kg/t dose of CS. There was an increase in all the strength properties with increase in AS dose (Figure 107).

4.4.2. At 350 kg/t of GCC

At 350 kg/t addition of GCC, the ash in paper was ~20.9-21.9% at all doses of AS; slightly higher than that with CS. At 10 kg/t dose of AS, all paper properties were comparable to those of reference. Gain in ash was around 3.5-4% (Figure 108).

4.4.3. At 400 kg/t of GCC

At this GCC addition level, the ash in paper was around 23-24.3% at all doses of AS; ~1% higher than that with CS. Except burst index all strength properties were on the lower side than those of reference. On increasing ash by 5.5-6%, the drop in breaking length, tear index and ZDTS was around 4-5% (Figure 109).

In case of GCC filler, the ash in paper could be increased from 18% to 21% and 23-24% with the usage of 10 and 15 kg/t dose of AS.

4.5. Effect of cationic strength additive and PCC filler on paper properties

The bulk of paper increased with the use of PCC as compared to that with talc. Optical properties viz. brightness, whiteness, opacity, and scattering coefficient increased significantly with PCC as compared to those with talc (Table 102-104).

4.5.1. At 290 kg/t of PCC

At 290 kg/t addition of PCC, the ash in paper at all doses of CS was approximately 18.5%. As expected, the physical properties of paper increased on increasing dose of CS (Figure 110).

4.5.2. At 370 kg/t of PCC

At 370 kg/t addition of PCC, the ash in paper was approximately 21.5%. At this ash level, all strength properties of paper using 10 kg/t dose of CS were more or less comparable to those of reference (18% ash with PCC and 5 kg/t dose of CS) except ZDTS which was not much affected with the increasing dose of CS. It was observed that CS was not effective on ZDTS when PCC was used as filler. On increasing dose of CS to15 kg/t, the strength properties were further increased (Figure 111).

4.5.3. At 420 kg/t of PCC

At this PCC addition level, the ash in paper was ~23.2-23.9%. At this ash level most of the strength properties were lower than those of reference even with the highest dose of CS (Figure 112).

In case of BWS and PCC filler, the ash in paper could be increased from 18% (reference) to 21.5% using 10 kg/t dose of CS or ~22-23% using 15 kg/t dose of CS with little compromise in ZDTS.

4.6. Effect of amphoteric strength additive and PCC filler on paper properties

The effect of different doses of AS with increasing PCC filler level in paper on various process and paper properties is shown in Table 105-107.

4.6.1. At 290 kg/t of PCC

At 290 kg/t addition of PCC, the ash in paper at all doses of CS was 18.5-19.3%. The paper properties were comparable with 5 kg/t dose of AS to those of reference i.e. same ash with 5 kg/t dose of CS. The paper strength was further increased on increasing the dose of AS (Figure 113).

4.6.2. At 370 kg/t of PCC

At 370 kg/t addition of PCC, the ash in paper was approximately 21.5%. At this ash level, similar to the case of CS, all strength properties of paper using 10 kg/t dose of AS were more or less comparable to those of reference except ZDTS which was little less. On increasing dose of AS to 15 kg/t, the strength properties were further increased (Figure 114).

4.6.3. At 420 kg/t of PCC

At this PCC addition level, the ash in paper was ~24%. At this ash level, most of the strength properties with the usage of 15 kg/t dose of AS were comparable to those of reference. The

drop in ZDTS was 7.2%. This showed that the AS was more effective on increasing the ash in paper with less compromise in paper strength than CS (Figure 115).

In case of BWS and PCC filler, the ash in paper could be increased from 18% (reference) to 24% using 15 kg/t dose of AS with little 7.2% compromise in ZDTS.

Table 86: Properties of BWS pulp with talc and cationic strength additive at 5 kg/t

Talc addition, %	Blank*	19	25	31	39
Retained ash, %	1.5	15.2	18.7	22.3	25.5
FPAR, %	-	85.8	86.0	87.9	85.5
Streaming potential, mV	-198	-173	-188	-180	-185
Charge demand, µeq/l	13.0	6.4	7.1	7.4	8.6
Zeta potential, mV	-17.4	-9.0	-10.0	-10.5	-10.7
Conductivity, mS	0.498	0.462	0.469	0.464	0.457
Bulk, cc/g	1.22	1.16	1.17	1.20	1.18
Breaking length, m	5310	4127	3662	3380	3186
Burst index, kN/g	2.95	2.26	2.12	1.93	1.75
Tear index, mNm^2/g	4.68	3.50	3.33	3.23	3.03
Bending stiffness, mNm	0.166	0.114	0.141	0.177	0.132
Double fold, no.	38	14	12	9	7
ZD tensile strength, kPa	738	733	694	671	652
Air permeance, Gurley s	47.5	26.2	26.3	26.0	21.3
Bendtsen roughness, ml/min	46	40	44	42	47
Brightness, %ISO	73.7	73.9	75.1	75.5	77.3
Opacity, %ISO	77.4	81.8	82.7	84.5	85.5
Scattering coefficient, m^2/kg	25.0	30.9	32.5	37.8	39.8
CIE whiteness	55.0	55.8	57.8	59.9	61.5
Yellowness	10.94	10.11	9.75	9.25	8.70
L*	91.8	91.7	92.2	92.4	92.8
a*	0.06	0.07	0.08	0.02	0.01
b*	5.37	5.18	5.02	4.78	4.54

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 5 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Blank: Unbeaten BWS pulp without addition of wet-end chemicals*

Table 87: Properties of BWS pulp with talc and cationic strength additive at 10 kg/t

Talc addition, %	Reference*	19	25	31	39
Retained ash, %	15.2	15.5	18.7	22.4	25.5
FPAR, %	85.8	87.7	86.0	88.3	85.5
Streaming potential, mV	-173	-212	-192	-161	-159
Charge demand, µeq/l	6.4	8.6	6.4	7.1	7.4
Zeta potential, mV	-9.0	-9.7	-8.7	-8.7	-6.2
Conductivity, mS	0.462	0.476	0.470	0.467	0.461
Bulk, cc/g	1.16	1.17	1.17	1.17	1.16
Breaking length, m	4127	4230	3858	3437	3284
Burst index, kN/g	2.26	2.31	2.12	1.99	1.87
Tear index, mNm^2/g	3.50	3.53	3.37	3.25	3.16
Bending stiffness, mNm	0.114	0.144	0.116	0.112	0.130
Double fold, no.	14	18	15	9	9
ZD tensile strength, kPa	733	745	716	698	683
Air permeance, Gurley s	26.2	31.2	25.0	20.2	18.2
Bendtsen roughness, ml/min	40	39	49	49	42
Brightness, %ISO	73.9	74.6	75.1	76.3	76.3
Opacity, %ISO	81.8	82.6	83.2	84.4	85.3
Scattering coefficient, m^2/kg	30.9	32.2	34.2	36.5	39.3
CIE whiteness	55.8	57.0	57.2	60.6	60.3
Yellowness	10.11	9.72	9.72	8.86	9.01
L*	91.7	91.8	91.9	92.5	92.5
a*	0.07	0.09	0.07	0.08	0.06
b*	5.18	4.98	4.99	4.57	4.65

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 10 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BWS with talc and CS, 5 kg/t at 15% ash level*

Table 88: Properties of BWS pulp with talc and cationic strength additive at 15 kg/t

Talc addition, %	Reference*	19	25	31	39
Retained ash, %	15.2	15.6	18.8	22.2	25.8
FPAR, %	85.8	88.3	86.5	87.5	86.6
Streaming potential, mV	-173	-145	-156	-165	-176
Charge demand, µeq/l	6.4	7.5	7.8	5.3	6.9
Zeta potential, mV	-9.0	-7.3	-7.5	-8.3	-9.4
Conductivity, mS	0.462	0.478	0.482	0.481	0.481
Bulk, cc/g	1.16	1.17	1.17	1.16	1.15
Breaking length, m	4127	4380	4086	3680	3432
Burst index, kN/g	2.26	2.47	2.34	2.07	1.93
Tear index, mNm^2/g	3.50	3.60	3.41	3.29	3.17
Bending stiffness, mNm	0.114	0.127	0.117	0.127	0.125
Double fold, no.	14	23	19	16	12
ZD tensile strength, kPa	733	750	725	706	692
Air permeance, Gurley s	26.2	31.8	28.5	26.2	25.3
Bendtsen roughness, ml/min	40	33	31	35	39
Brightness, %ISO	73.9	73.6	74.6	75.2	76.4
Opacity, %ISO	81.8	81.9	83.3	84.3	85.1
Scattering coefficient, m^2/kg	30.9	31.0	33.7	35.4	34.4
CIE whiteness	55.8	55.9	56.8	57.5	60.3
Yellowness	10.11	10.03	9.86	9.85	9.15
L*	91.7	91.6	91.8	92.1	92.6
a*	0.07	0.11	0.09	0.14	0.10
b*	5.18	5.12	5.05	5.04	4.71

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 15 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BWS with talc and CS, 5 kg/t at 15% ash level*

Table 89: Properties of BWS pulp with talc and amphoteric strength additive at 5 kg/t

Talc addition, %	Reference*	19	25	31
Retained ash, %	15.2	15.5	18.6	22.3
FPAR, %	85.8	87.7	85.5	87.9
Streaming potential, mV	-173	-205	-210	-219
Charge demand, µeq/l	6.4	5.3	6.4	6.8
Zeta potential, mV	-9.0	-8.0	-8.9	-7.7
Conductivity, mS	0.462	0.485	0.478	0.478
Bulk, cc/g	1.16	1.17	1.17	1.16
Breaking length, m	4127	4131	3697	3746
Burst index, kN/g	2.26	2.30	2.18	1.93
Tear index, mNm^2/g	3.50	3.62	3.48	3.30
Bending stiffness, mNm	0.114	0.134	0.120	0.120
Double fold, no.	14	17	14	12
ZD tensile strength, kPa	733	759	739	710
Air permeance, Gurley s	26.2	28.8	24.2	21.7
Bendtsen roughness, ml/min	40	41	45	46
Brightness, %ISO	73.9	74.5	75.1	76.4
Opacity, %ISO	81.8	81.5	82.7	83.4
Scattering coefficient, m^2/kg	30.9	31.5	33.6	34.6
CIE whiteness	55.8	57.2	58.3	60.2
Yellowness	10.11	9.91	9.65	9.19
L*	91.7	92.1	92.3	92.6
a*	0.07	0.11	0.09	0.12
b*	5.18	5.08	4.97	4.72

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 5 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BWS with talc and CS, 5 kg/t at 15% ash level*

Table 90: Properties of BWS pulp with talc and amphoteric strength additive at 10 kg/t

Talc addition, %	Reference*	19	25	31	39
Retained ash, %	15.2	15.5	18.6	22.5	25.7
FPAR, %	85.8	87.7	85.5	88.7	86.3
Streaming potential, mV	-173	-201	-316	-301	-325
Charge demand, µeq/l	6.4	7.7	5.0	5.5	6.9
Zeta potential, mV	-9.0	-5.6	-4.1	-4.7	-5.1
Conductivity, mS	0.462	0.458	0.463	0.461	0.453
Bulk, cc/g	1.16	1.18	1.18	1.15	0.00
Breaking length, m	4127	4416	4262	3786	3524
Burst index, kN/g	2.26	2.48	2.47	2.15	2.05
Tear index, mNm^2/g	3.50	3.68	3.48	3.29	3.06
Bending stiffness, mNm	0.114	0.153	0.119	0.124	0.119
Double fold, no.	14	25	18	15	12
ZD tensile strength, kPa	733	767	750	736	702
Air permeance, Gurley s	26.2	27.0	27.5	23.8	23.5
Bendtsen roughness, ml/min	40	32	35	36	34
Brightness, %ISO	73.9	74.2	74.3	75.6	76.7
Opacity, %ISO	81.8	81.3	82.6	83.0	83.5
Scattering coefficient, m^2/kg	30.9	30.3	31.2	33.7	36.0
CIE whiteness	55.8	56.6	57.4	59.6	61.3
Yellowness	10.11	10.04	9.82	9.32	8.93
L*	91.7	91.9	92.1	92.5	92.8
a*	0.07	0.14	0.12	0.11	0.10
b*	5.18	5.13	5.03	4.79	4.60

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 10 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BWS with talc and CS, 5 kg/t at 15% ash level*

Table 91: Properties of BWS pulp blended with MHW (85% BWS + 15% MHW) with talc and cationic strength additive at 5 kg/t

Talc addition, %	Blank*	19	25	31	39
Retained ash, %	1.5	14.1	18.7	20.7	24.8
FPAR, %	-	78.9	86.0	81.1	83.0
Streaming potential, mV	-200	-191	-186	-200	-167
Charge demand, µeq/l	14.8	5.8	6.4	7.5	8.5
Zeta potential, mV	-19.9	-10.6	-11.8	-13.1	-14.2
Conductivity, mS	0.515	0.503	0.497	0.486	0.481
Bulk, cc/g	1.23	1.19	1.20	1.21	1.18
Breaking length, m	5345	4135	3785	3643	3567
Burst index, kN/g	3.11	2.52	2.39	2.04	1.88
Tear index, mNm^2/g	4.74	3.78	3.56	3.35	3.20
Bending stiffness, mNm	0.173	0.155	0.131	0.122	0.213
Double fold, no.	22	13	19	9	9
Air permeance, Gurley s	22.1	17.3	12.6	12.0	10.9
Bendtsen roughness, ml/min	45	41	43	53	45
Brightness, %ISO	75.4	75.6	75.3	76.4	76.8
Opacity, %ISO	78.3	79.3	82.6	80.0	83.8
Scattering coefficient, m^2/kg	26.7	27.8	31.8	31.6	34.1
CIE whiteness	58.6	58.3	59.4	60.9	62.0
Yellowness	9.43	9.38	9.14	8.79	8.44
L*	92.2	91.9	92.2	92.5	92.6
a*	0.10	0.15	0.16	0.14	0.13
b*	4.84	4.78	4.66	4.49	4.31

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 5 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Blank: Unbeaten BWS and beaten MHW pulp (30 ^oSR) without addition of wet-end chemical*

Table 92: Properties of BWS pulp blended with MHW (85% BWS + 15% MHW) with talc and cationic strength additive at 5 kg/t

Particular	Experimental Values				
Retained ash, %	0	15	18	21	24
Breaking length, m	5345	4108	3901	3694	3487
Burst index, kN/g	3.11	2.48	2.29	2.09	1.90
Tear index, mNm^2/g	4.89	3.76	3.61	3.45	3.30
	Weighted Average Values				
Breaking length, m	5301	4132	3856	3581	3305
Burst index, kN/g	3.06	2.39	2.20	2.02	1.84
Tear index, mNm^2/g	5.04	3.70	3.60	3.49	3.38
	100% BWS Pulp properties				
Breaking length, m	5310	4005	3756	3507	3258
Burst index, kN/g	2.95	2.30	2.13	1.97	1.80
Tear index, mNm^2/g	4.68	3.34	3.26	3.17	3.08
	100% MHW Pulp properties				
Breaking length, m	5251	4849	4423	3997	3571
Burst index, kN/g	3.68	2.86	2.60	2.35	2.10
Tear index, mNm^2/g	7.11	5.74	5.52	5.29	5.07

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 5 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

Table 93: Properties of BWS pulp blended with SW (95% BWS + 5% SW) with talc and cationic strength additive at 5 kg/t

Talc addition, %	Blank*	19	24.5	30	37
Retained ash, %	1.5	14.3	17.8	21.1	24.1
FPAR, %	-	80.2	82.8	84.9	83.7
Streaming potential, mV	-166	-105	-115	-132	-150
Charge demand, µeq/l	14.5	7.3	8.5	9.1	10.5
Zeta potential, mV	-20.6	-11.4	-12.4	-12.8	-13.2
Conductivity, mS	0.492	0.464	0.473	0.470	0.478
Bulk, cc/g	1.27	1.21	1.20	1.18	1.18
Breaking length, m	4559	3514	3450	3245	3036
Burst index, kN/g	3.23	2.34	2.28	1.98	1.83
Tear index, mNm^2/g	5.14	4.33	4.18	3.94	3.79
Bending stiffness, mNm	0.164	0.138	0.126	0.120	0.117
Double fold, no.	22	18	14	13	12
Air permeance, Gurley s	11.5	8.8	7.4	7.1	6.7
Bendtsen roughness, ml/min	62	62	67	66	70
Brightness, %ISO	76.1	75.1	75.9	76.4	76.8
Opacity, %ISO	79.6	82.8	83.6	83.9	84.4
Scattering coefficient, m^2/kg	31.7	34.0	34.6	35.2	37.3
CIE whiteness	61.7	59.1	61.2	61.8	62.8
Yellowness	8.58	9.04	8.55	8.33	8.12
L*	92.6	91.9	92.3	92.4	92.6
a*	0.13	0.23	-0.20	0.20	0.20
b*	4.39	4.56	4.33	4.27	4.12

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 5 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Blank: Unbeaten BWS and beaten SW pulp (25 ^oSR) without addition of wet-end chemical*

Table 94: Properties of BWS pulp blended with SW (95% BWS + 5% SW) with talc and cationic strength additive at 5, 10 and 15 kg/t

Talc addition, %	Blank*	30			37		
CS, kg/t	0	5	10	15	5	10	15
Retained ash, %	1.5	21.1	21.2	21.2	24.1	24.2	24.3
FPAR, %	-	84.9	85.4	85.4	83.7	84.1	84.4
Streaming potential, mV	-166	-132	-100	-60	-150	-110	-75
Charge demand, µeq/l	14.5	9.1	8.0	6.3	10.5	9.2	7.8
Zeta potential, mV	-20.6	-12.8	-11.0	-7.7	-13.2	-11.9	-8.5
Conductivity, mS	0.492	0.470	0.474	0.468	0.478	0.473	0.465
Bulk, cc/g	1.27	1.18	1.17	1.17	1.18	1.19	1.18
Breaking length, m	4559	3245	3342	3553	3036	3225	3350
Burst index, kN/g	3.23	1.98	2.01	2.05	1.83	1.86	1.89
Tear index, mNm^2/g	5.14	3.94	4.03	4.08	3.79	3.85	3.90
Bending stiffness, mNm	0.164	0.120	0.128	0.129	0.117	0.120	0.129
Double fold, no.	22	13	14	17	12	12	13
Air permeance, Gurley s	11.6	7.1	8.1	8.0	6.7	7.5	7.3
Bendtsen roughness, ml/min	62	66	60	60	70	67	71
Brightness, %ISO	76.1	76.4	76.0	75.9	76.8	76.7	76.6
Opacity, %ISO	79.6	83.9	83.8	83.4	84.4	84.4	84.2
Scattering coefficient, m^2/kg	31.7	35.2	34.3	33.7	37.3	35.2	34.2
CIE whiteness	61.7	61.8	60.9	60.40	62.8	62.1	62.3
Yellowness	8.58	8.33	8.51	8.54	8.12	8.24	8.14
L*	92.6	92.4	92.1	92.1	92.6	92.4	92.3
a*	0.13	0.20	0.20	0.21	0.20	0.18	0.17
b*	4.39	4.27	4.31	4.31	4.12	4.18	4.13

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Blank: Unbeaten BWS and beaten SW pulp (25 ^oSR) without addition of wet-end chemical*

Table 95: Properties of BWS pulp blended with SW (95% BWS + 5% SW) with talc and amphoteric strength additive at 5, 10 and 15 kg/t

Talc addition, %	Blank*	30			37		
AS, kg/t	0	5	10	15	5	10	15
Retained ash, %	1.5	21.2	21.2	21.3	24.1	24.3	24.3
FPAR, %	-	85.4	85.4	85.8	83.7	84.4	84.4
Streaming potential, mV	-166	-127	-95	-95	-140	-100	-80
Charge demand, µeq/l	14.5	7.8	6.1	5.5	6.9	6.8	6.8
Zeta potential, mV	-20.6	-13.7	-9.1	-6.1	-15.1	-9.4	-6.6
Conductivity, mS	0.492	0.481	0.463	0.465	0.461	0.464	0.467
Bulk, cc/g	1.27	1.18	1.18	1.19	1.17	1.17	1.16
Breaking length, m	4559	3250	3304	3642	3053	3049	3394
Burst index, kN/g	3.23	2.13	2.15	2.25	1.83	1.86	2.08
Tear index, mNm^2/g	5.14	3.97	4.04	4.10	3.84	3.91	3.91
Bending stiffness, mNm	0.164	0.110	0.139	0.114	0.120	0.116	0.117
Double fold, no.	22	13	15	22	11	13	18
Air permeance, Gurley s	11.5	7.8	8.0	9.1	7.0	7.1	8.0
Bendtsen roughness, ml/min	62	66	64	68	66	64	61
Brightness, %ISO	76.1	76.1	75.8	75.5	76.9	76.4	76.2
Opacity, %ISO	79.6	83.8	83.9	84.1	84.0	84.4	84.7
Scattering coefficient, m^2/kg	31.7	34.3	34.4	34.4	35.2	34.5	33.2
CIE whiteness	61.7	61.4	60.6	60.6	62.3	61.9	61.7
Yellowness	8.58	8.38	8.60	8.80	8.23	8.27	8.48
L*	92.6	92.2	92.1	92.3	90.4	92.4	92.4
a*	0.13	0.18	0.20	0.21	0.19	0.15	0.23
b*	4.39	4.25	4.35	4.46	4.18	4.21	4.23

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Blank: Unbeaten BWS and beaten SW pulp (25 ^oSR) without addition of wet-end chemical*

Table 96: Properties of BWS pulp with GCC and cationic strength additive at 5 kg/t

GCC addition, %	Blank*	29	35	40
Retained ash, %	2.0	18.3	20.7	23.1
FPAR, %	--	72.5	72.1	73.9
Streaming potential, mV	-143	-181	-190	-185
Charge demand, µeq/l	26.0	5.8	5.5	5.1
Zeta potential, mV	-12.8	-8.1	-7.9	-7.6
Conductivity, mS	0.590	0.481	0.487	0.485
Bulk, cc/g	1.41	1.35	1.36	1.34
Breaking length, m	4427	3001	2901	2797
Burst index, kN/g	3.06	1.98	1.90	1.67
Tear index, mNm^2/g	4.84	4.06	3.83	3.55
Bending stiffness, mNm	0.149	0.120	0.121	0.114
Double fold, no.	26	8	7	8
ZD tensile strength, kPa	716	650	634	594
Wax pick no.	12	9	8	8
Air permeance, Gurley s	59.8	39.7	38.9	38.1
Bendtsen roughness, ml/min	143	132	132	127
Brightness, %ISO	81.6	83.0	83.4	83.5
Opacity, %ISO	81.3	87.0	87.8	88.3
Scattering coefficient, m^2/kg	36.5	52.0	54.4	55.0
CIE whiteness	67.6	71.4	71.9	72.6
Yellowness	8.02	6.61	6.61	6.35
L*	94.8	94.9	95.1	95.1
a*	-0.15	-0.07	-0.07	-0.08
b*	4.30	3.51	3.51	3.38

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 5 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Blank: Unbeaten BWS pulp without addition of wet-end chemicals*

Table 97: Properties of BWS pulp with GCC and cationic strength additive at 10 kg/t

GCC addition, %	Reference*	29	35	40
Retained ash, %	18.3	17.8	21.2	23.2
FPAR, %	72.5	70.3	74.1	74.2
Streaming potential, mV	-181	-171	-182	-189
Charge demand, µeq/l	5.8	5.4	5.2	4.9
Zeta potential, mV	-8.1	-7.8	-7.5	-7.1
Conductivity, mS	0.481	0.471	0.474	0.472
Bulk, cc/g	1.35	1.31	1.34	1.30
Breaking length, m	3001	3074	2972	2855
Burst index, kN/g	1.98	2.15	2.04	2.00
Tear index, mNm^2/g	4.06	4.13	3.96	3.66
Bending stiffness, mNm	0.120	0.115	0.118	0.123
Double fold, no.	8	11	10	8
ZD tensile strength, kPa	650	658	644	616
Wax pick no.	9	7	7	7
Air permeance, Gurley s	39.7	56.1	48.8	44.8
Bendtsen roughness, ml/min	132	117	105	107
Brightness, %ISO	83.0	82.5	83.2	83.4
Opacity, %ISO	87.0	87.0	87.5	87.9
Scattering coefficient, m^2/kg	52.0	46.1	51.1	54.2
CIE whiteness	71.4	70.6	71.9	72.8
Yellowness	6.61	6.70	6.46	6.08
L*	94.9	94.6	95.0	95.0
a*	-0.07	-0.08	-0.09	-0.05
b*	3.51	3.55	3.43	3.22

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 10 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BWS with GCC and CS, 5 kg/t at 18% ash level*

Table 98: Properties of BWS pulp with GCC and cationic strength additive at 15 kg/t

GCC addition, %	Reference*	29	35	40
Retained ash, %	18.3	17.7	20.9	23.0
FPAR, %	72.5	69.8	72.9	73.5
Streaming potential, mV	-181	-170	-180	-181
Charge demand, µeq/l	5.8	5.1	4.9	4.7
Zeta potential, mV	-8.1	-7.6	-7.2	-7.0
Conductivity, mS	0.481	0.461	0.464	0.460
Bulk, cc/g	1.35	1.32	1.27	1.28
Breaking length, m	3001	3129	3039	2945
Burst index, kN/g	1.98	2.23	2.17	2.07
Tear index, mNm^2/g	4.06	4.33	4.15	3.82
Bending stiffness, mNm	0.120	0.119	0.116	0.094
Double fold, no.	8	13	13	10
ZD tensile strength, kPa	650	662	652	628
Wax pick no.	9	8	7	8
Air permeance, Gurley s	39.7	54.8	57.3	52.0
Bendtsen roughness, ml/min	132	120	112	107
Brightness, %ISO	83.0	82.0	82.3	82.6
Opacity, %ISO	87.0	87.2	87.4	87.7
Scattering coefficient, m^2/kg	52.0	46.7	48.8	47.4
CIE whiteness	71.4	70.1	71.2	71.4
Yellowness	6.61	6.81	6.41	6.48
L*	94.9	94.6	94.5	94.8
a*	-0.07	-0.09	-0.06	-0.04
b*	3.51	3.61	3.38	3.42

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 15 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BWS with GCC and CS, 5 kg/t at 18% ash level*

Table 99: Properties of BWS pulp with GCC and amphoteric strength additive at 5 kg/t

GCC addition, %	Reference*	29	35	40
Retained ash, %	18.3	19.4	20.9	23.0
FPAR, %	72.5	77.4	72.9	73.5
Streaming potential, mV	-181	-130	-125	-118
Charge demand, µeq/l	5.8	7.1	6.9	6.1
Zeta potential, mV	-8.1	-5.4	-5.2	5.1
Conductivity, mS	0.481	0.510	0.498	0.499
Bulk, cc/g	1.35	1.33	1.34	1.32
Breaking length, m	3001	2853	2793	2549
Burst index, kN/g	1.98	2.01	1.94	1.63
Tear index, mNm^2/g	4.06	4.09	3.82	3.58
Bending stiffness, mNm	0.120	0.136	0.118	0.104
Double fold, no.	8	12	10	7
ZD tensile strength, kPa	650	644	614	569
Wax pick no.	9	10	9	7
Air permeance, Gurley s	39.7	29.8	26.2	24.8
Bendtsen roughness, ml/min	132	129	122	132
Brightness, %ISO	83.0	83.2	83.6	84.1
Opacity, %ISO	87.5	87.1	87.6	88.4
Scattering coefficient, m^2/kg	52.0	51.4	52.3	55.0
CIE whiteness	71.4	71.7	72.2	73.1
Yellowness	6.61	6.44	6.37	6.99
L*	94.9	94.8	94.9	95.0
a*	-0.07	0.01	-0.02	-0.02
b*	3.51	3.38	3.36	3.15

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 5 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BWS with GCC and CS, 5 kg/t at 18% ash level*

Table 100: Properties of BWS pulp with GCC and amphoteric strength additive at 10 kg/t

GCC addition, %	Reference*	29	35	40
Retained ash, %	18.3	19.5	21.8	24.1
FPAR, %	72.5	77.8	76.4	77.4
Streaming potential, mV	-181	-128	-121	-114
Charge demand, µeq/l	5.8	6.9	6.4	5.8
Zeta potential, mV	-8.1	-4.9	-5.1	-4.9
Conductivity, mS	0.481	0.500	0.491	0.489
Bulk, cc/g	1.35	1.29	1.28	1.28
Breaking length, m	3001	3190	2914	2874
Burst index, kN/g	1.98	2.23	2.08	1.97
Tear index, mNm^2/g	4.06	4.13	3.97	3.71
Bending stiffness, mNm	0.120	0.106	0.114	0.104
Double fold, no.	8	14	11	8
ZD tensile strength, kPa	650	654	625	598
Wax pick no.	9	7	7	7
Air permeance, Gurley s	39.7	30.9	27.0	24.0
Bendtsen roughness, ml/min	132	86	107	108
Brightness, %ISO	83.0	82.0	82.6	83.3
Opacity, %ISO	87.5	87.0	87.6	88.1
Scattering coefficient, m^2/kg	52.0	49.7	50.2	52.4
CIE whiteness	71.4	70.1	71.5	72.6
Yellowness	6.61	6.76	6.52	6.11
L*	94.9	94.5	94.7	94.9
a*	-0.07	-0.04	-0.03	-0.04
b*	3.51	3.56	3.43	3.22

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 10 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BWS with GCC and CS, 5 kg/t at 18% ash level*

Table 101: Properties of BWS pulp with GCC and amphoteric strength additive at 15 kg/t

GCC addition, %	Reference*	29	35	40
Retained ash, %	18.3	18.9	21.9	24.3
FPAR, %	72.5	75.2	76.8	78.1
Streaming potential, mV	-181	-121	-119	-111
Charge demand, µeq/l	5.8	6.3	6.1	5.4
Zeta potential, mV	-8.1	-4.6	-5.0	-4.8
Conductivity, mS	0.481	0.495	0.489	0.480
Bulk, cc/g	1.35	1.28	1.27	1.26
Breaking length, m	3001	3240	2914	2887
Burst index, kN/g	1.98	2.26	2.17	2.02
Tear index, mNm^2/g	4.06	4.22	4.00	3.86
Bending stiffness, mNm	0.120	0.091	0.108	0.086
Double fold, no.	8	15	12	9
ZD tensile strength, kPa	650	663	640	619
Wax pick no.	9	8	8	8
Air permeance, Gurley s	39.7	30.5	27.1	25.5
Bendtsen roughness, ml/min	132	124	112	109
Brightness, %ISO	83.0	81.6	82.4	82.8
Opacity, %ISO	87.5	86.4	87.2	87.9
Scattering coefficient, m^2/kg	52.0	44.9	46.6	49.6
CIE whiteness	71.4	69.7	70.7	71.8
Yellowness	6.61	6.90	6.60	6.35
L*	94.9	94.4	94.6	94.7
a*	-0.07	-0.06	-0.09	-0.04
b*	3.51	3.64	3.50	3.35

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 15 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BWS with GCC and CS, 5 kg/t at 18% ash level*

Table 102: Properties of BWS pulp with PCC and cationic strength additive at 5 kg/t

PCC addition, %	Blank*	23	29	37
Retained ash, %	2.0	15.5	18.4	21.6
FPAR, %	--	72.2	73.0	72.6
Streaming potential, mV	-143	-105	-108	-112
Charge demand, µeq/l	26.0	5.8	6.1	6.4
Zeta potential, mV	-12.8	-9.0	-9.3	-9.7
Conductivity, mS	0.590	0.412	0.428	0.438
Bulk, cc/g	1.41	1.43	1.45	1.48
Breaking length, m	4427	3028	2696	2468
Burst index, kN/g	3.06	2.05	1.84	1.68
Tear index, mNm^2/g	4.84	4.56	4.22	4.05
Bending stiffness, mNm	0.149	0.147	0.130	0.124
Double fold, no.	26	10	7	6
ZD tensile strength, kPa	716	627	586	553
Wax pick no.	12	10	9	9
Air permeance, Gurley s	59.8	34.3	26.8	21.5
Bendtsen roughness, ml/min	156	150	151	151
Brightness, %ISO	81.6	83.2	84.2	84.7
Opacity, %ISO	81.3	87.5	88.6	88.9
Scattering coefficient, m^2/kg	36.5	50.4	54.0	58.5
CIE whiteness	67.6	72.0	73.5	74.2
Yellowness	8.02	6.45	6.13	5.98
L*	94.8	94.9	95.2	95.4
a*	-0.15	0.00	0.04	0.01
b*	4.30	3.39	3.21	3.16

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 5 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Blank: Unbeaten BWS pulp without addition of wet-end chemicals*

Table 103: Properties of BWS pulp with PCC and cationic strength additive at 10 kg/t

PCC addition, %	Reference*	29	37	42
Retained ash, %	18.4	18.8	21.6	23.2
FPAR, %	73.0	74.7	72.6	71.7
Streaming potential, mV	-108	-101	-105	-106
Charge demand, µeq/l	6.1	5.4	5.9	6.1
Zeta potential, mV	-9.3	-9.0	-9.3	-9.7
Conductivity, mS	0.428	0.401	0.411	0.418
Bulk, cc/g	1.45	1.46	1.46	1.50
Breaking length, m	2596	2951	2748	2332
Burst index, kN/g	1.84	1.88	1.86	1.70
Tear index, mNm^2/g	4.22	4.35	4.16	3.92
Bending stiffness, mNm	0.130	0.137	0.131	0.122
Double fold, no.	7	11	7	5
ZD tensile strength, kPa	586	591	559	526
Wax pick no.	9	6	6	6
Air permeance, Gurley s	26.8	25.5	25.5	20.5
Bendtsen roughness, ml/min	151	160	152	148
Brightness, %ISO	84.2	83.0	83.3	84.3
Opacity, %ISO	88.6	88.1	88.3	88.7
Scattering coefficient, m^2/kg	54.0	55.2	57.9	60.3
CIE whiteness	73.5	71.4	72.0	73.9
Yellowness	6.13	6.60	6.50	5.99
L*	95.2	94.9	95.1	95.3
a*	0.04	-0.10	-0.10	-0.06
b*	3.21	3.50	3.50	3.18

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 10 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: BWS with PCC and CS, 5 kg/t at 18% ash level*

Table 104: Properties of BWS pulp with PCC and cationic strength additive at 15 kg/t

PCC addition, %	Reference*	29	37	42
Retained ash, %	18.4	18.5	21.2	23.9
FPAR, %	73.0	73.4	71.1	74.0
Streaming potential, mV	-108	-104	-106	-109
Charge demand, µeq/l	6.1	5.3	5.6	5.8
Zeta potential, mV	0.428	-8.8	-9.0	-9.1
Conductivity, mS	-9.3	0.411	0.419	0.426
Bulk, cc/g	1.45	1.43	1.46	1.46
Breaking length, m	2596	3073	2890	2511
Burst index, kN/g	1.84	2.21	2.02	1.91
Tear index, mNm^2/g	4.22	4.59	4.36	3.96
Bending stiffness, mNm	0.130	0.139	0.146	0.124
Double fold, no.	7	13	12	9
ZD tensile strength, kPa	586	608	562	530
Wax pick no.	9	7	7	7
Air permeance, Gurley s	26.8	31.7	27.4	24.1
Bendtsen roughness, ml/min	151	155	149	141
Brightness, %ISO	84.2	82.8	83.5	84.3
Opacity, %ISO	88.6	88.2	88.6	89.1
Scattering coefficient, m^2/kg	54.0	54.1	57.0	59.8
CIE whiteness	73.5	72.0	72.8	74.9
Yellowness	6.13	6.40	6.21	5.65
L*	95.2	94.9	95.0	95.4
a*	0.04	-0.05	-0.05	-0.06
b*	3.21	3.39	3.29	3.00

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 15 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: BWS with PCC and CS, 5 kg/t at 18% ash level*

Table 105: Properties of BWS pulp with PCC and amphoteric strength additive at 5 kg/t

PCC addition, %	Reference*	29	37	42
Retained ash, %	18.4	19.0	21.7	23.9
FPAR, %	73.0	75.6	72.9	74.0
Streaming potential, mV	-108	-98	-122	-124
Charge demand, µeq/l	6.1	5.8	6.0	6.2
Zeta potential, mV	0.428	0.418	0.428	0.431
Conductivity, mS	-9.3	-7.8	-8.2	-8.5
Bulk, cc/g	1.45	1.45	1.48	1.47
Breaking length, m	2596	2873	2601	2451
Burst index, kN/g	1.84	1.93	1.80	1.68
Tear index, mNm^2/g	4.22	4.17	4.00	3.85
Bending stiffness, mNm	0.130	0.128	0.146	0.128
Double fold, no.	7	7	6	6
ZD tensile strength, kPa	586	566	540	534
Wax pick no.	9	7	7	6
Air permeance, Gurley s	26.8	28.2	23.1	21.6
Bendtsen roughness, ml/min	151	163	187	138
Brightness, %ISO	84.2	83.2	83.9	84.2
Opacity, %ISO	88.6	88.6	89.0	89.4
Scattering coefficient, m^2/kg	54.0	55.1	58.6	60.4
CIE whiteness	73.5	71.7	73.4	74.0
Yellowness	6.13	6.70	6.25	6.10
L*	95.2	95.0	95.3	95.4
a*	0.04	0.02	0.02	0.03
b*	3.21	3.52	3.29	3.20

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 5 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: BWS with PCC and CS, 5 kg/t at 18% ash level*

Table 106: Properties of BWS pulp with PCC and amphoteric strength additive at 10 kg/t

PCC addition, %	Reference*	29	37	42
Retained ash, %	18.4	19.3	22.0	24.0
FPAR, %	73.0	77.0	74.0	74.4
Streaming potential, mV	-108	-100	-112	-119
Charge demand, µeq/l	6.1	5.6	5.9	6.0
Zeta potential, mV	0.428	0.411	0.414	0.421
Conductivity, mS	-9.3	-7.5	-8.0	-7.9
Bulk, cc/g	1.45	1.45	1.46	1.48
Breaking length, m	2596	2875	2722	2445
Burst index, kN/g	1.84	2.15	1.93	1.76
Tear index, mNm^2/g	4.22	4.32	4.22	3.90
Bending stiffness, mNm	0.130	0.143	0.133	0.130
Double fold, no.	7	9	9	6
ZD tensile strength, kPa	586	619	568	544
Wax pick no.	9	7	7	6
Air permeance, Gurley s	26.8	25.8	23.6	22.0
Bendtsen roughness, ml/min	151	207	201	179
Brightness, %ISO	84.2	83.3	84.1	84.0
Opacity, %ISO	88.6	88.5	88.9	89.2
Scattering coefficient, m^2/kg	54.0	55.9	58.1	60.2
CIE whiteness	73.5	73.2	74.6	74.9
Yellowness	6.13	6.02	5.74	5.56
L*	95.2	95.0	95.3	95.2
a*	0.04	-0.06	-0.07	-0.05
b*	3.21	3.19	3.05	2.95

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 10 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: BWS with PCC and CS, 5 kg/t at 18% ash level*

Table 107: Properties of BWS pulp with PCC and amphoteric strength additive at 15 kg/t

PCC addition, %	Reference*	29	37	42
Retained ash, %	18.4	18.5	21.4	23.8
FPAR, %	73.0	73.4	71.8	73.7
Streaming potential, mV	-108	-97	-111	-114
Charge demand, µeq/l	6.1	5.4	5.7	5.9
Zeta potential, mV	0.428	0.405	0.410	0.415
Conductivity, mS	-9.3	-7.2	-8.1	-8.2
Bulk, cc/g	1.45	1.43	1.44	1.45
Breaking length, m	2596	2946	2731	2650
Burst index, kN/g	1.84	2.19	1.95	1.86
Tear index, mNm^2/g	4.22	4.48	4.32	4.15
Bending stiffness, mNm	0.130	0.135	0.122	0.121
Double fold, no.	7	12	9	7
ZD tensile strength, kPa	586	620	566	544
Wax pick no.	9	7	6	7
Air permeance, Gurley s	26.8	29.5	28.0	22.6
Bendtsen roughness, ml/min	151	146	140	138
Brightness, %ISO	84.2	83.1	83.7	84.0
Opacity, %ISO	88.6	88.4	88.7	89.2
Scattering coefficient, m^2/kg	54.0	54.4	56.3	60.1
CIE whiteness	73.5	72.9	74.1	75.1
Yellowness	6.13	5.96	5.67	5.29
L*	95.2	94.9	95.0	95.1
a*	0.04	-0.08	-0.04	-0.07
b*	3.21	3.16	3.00	2.81

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 15 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: BWS with PCC and CS, 5 kg/t at 18% ash level*

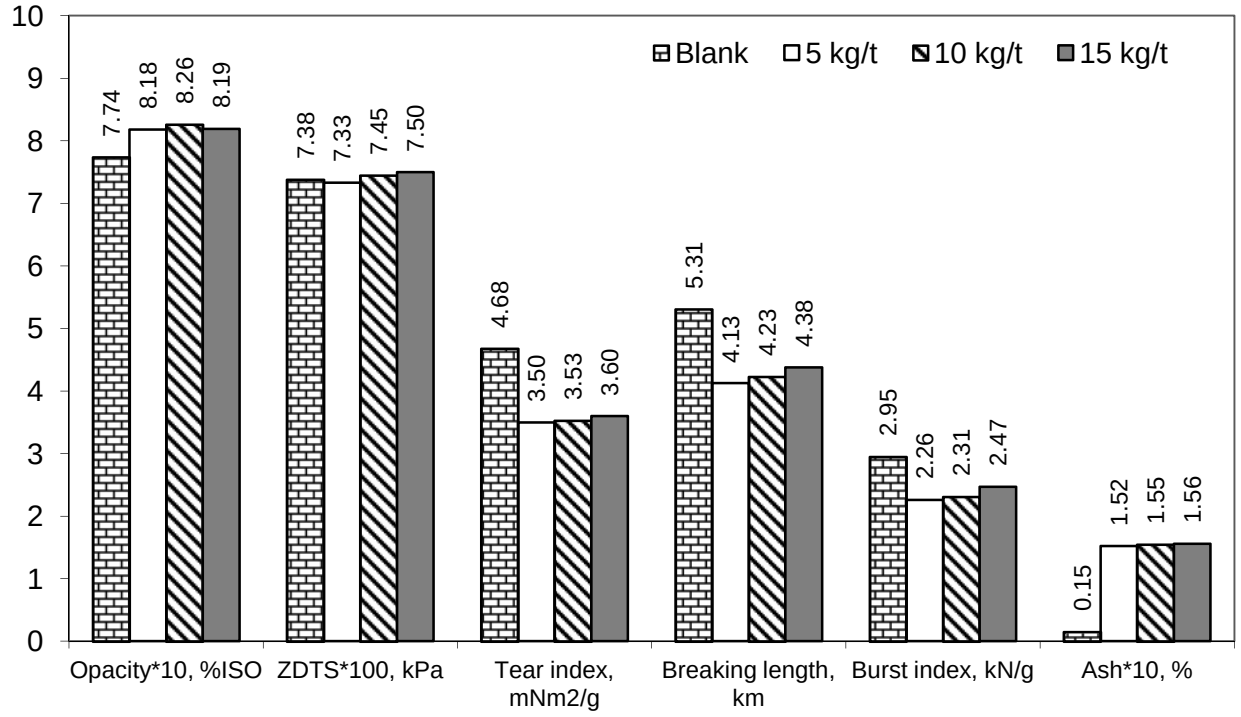

Figure 97: Effect of CS on properties of BWS pulp at 190 kg/t addition of talc

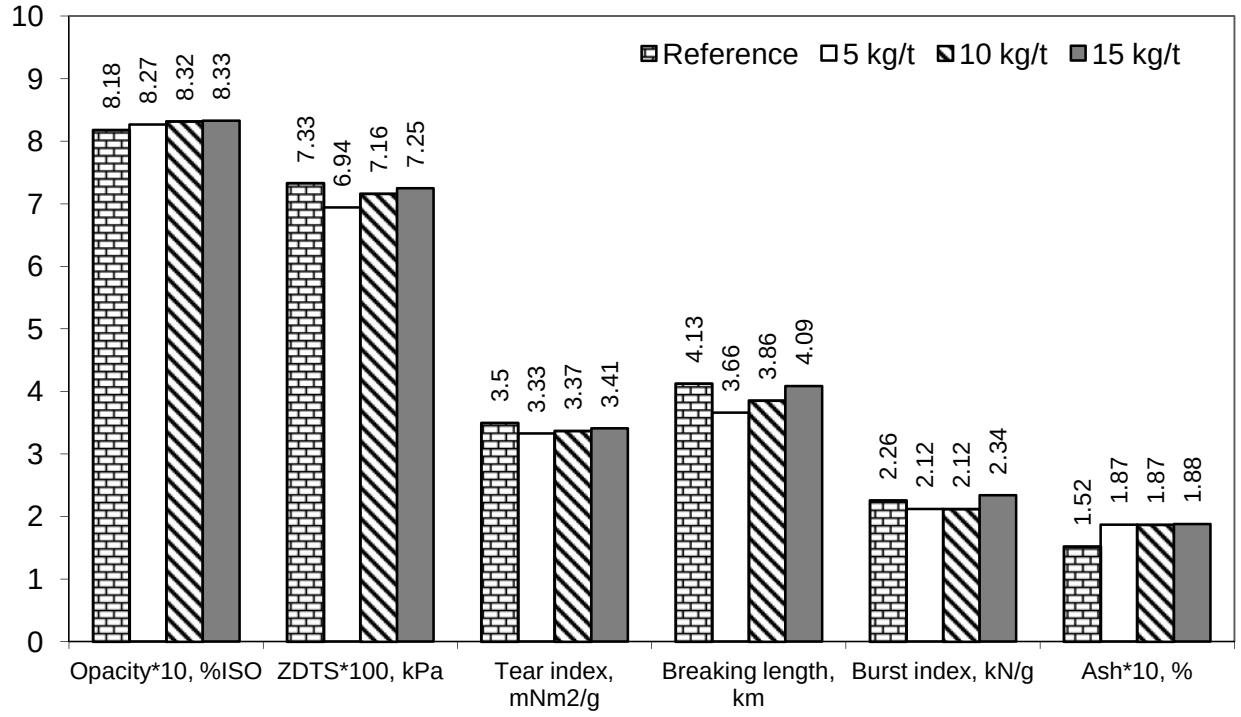

Figure 98: Effect of CS on properties of BWS pulp at 250 kg/t addition of talc

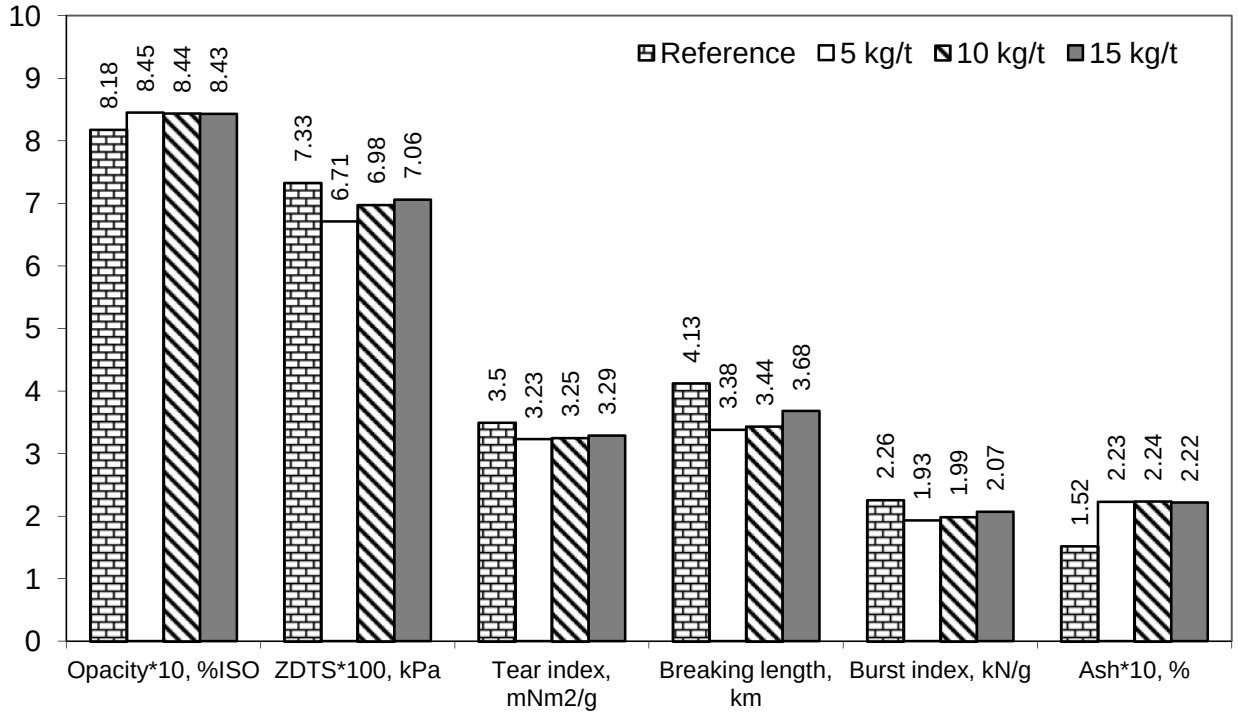

Figure 99: Effect of CS on properties of BWS pulp at 310 kg/t addition of talc

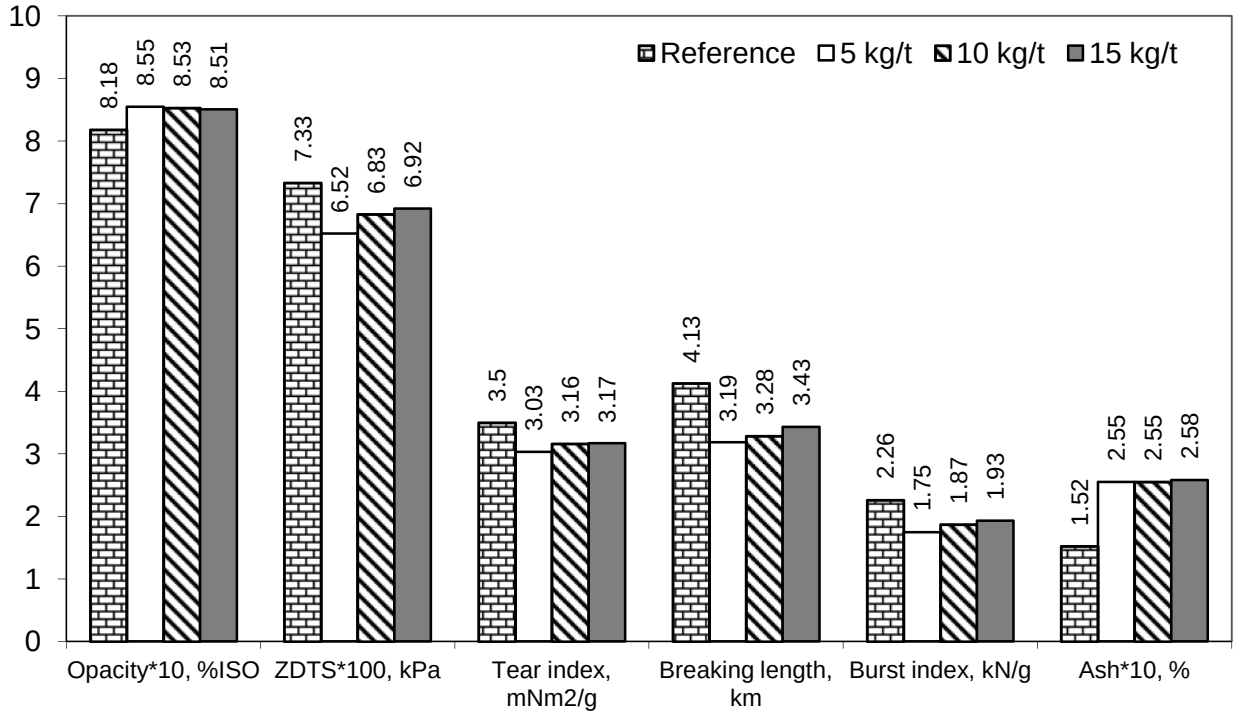

Figure 100: Effect of CS on properties of BWS pulp at 390 kg/t addition of talc

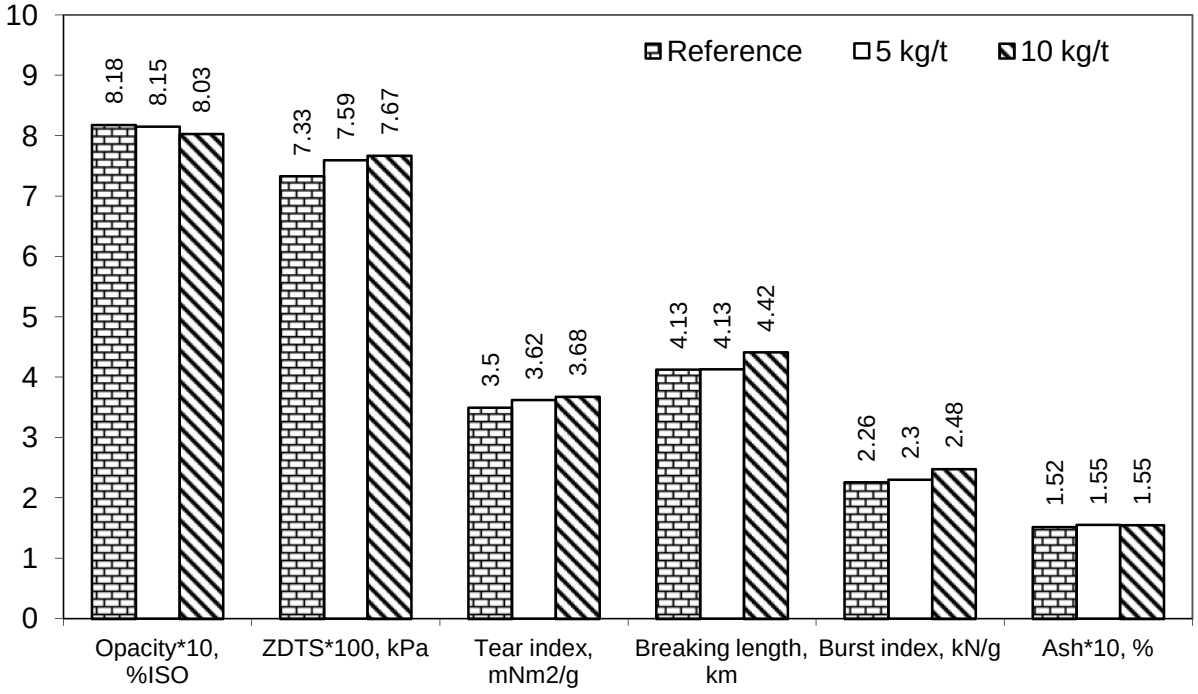

Figure 101: Effect of AS on properties of BWS pulp at 190 kg/t addition of talc

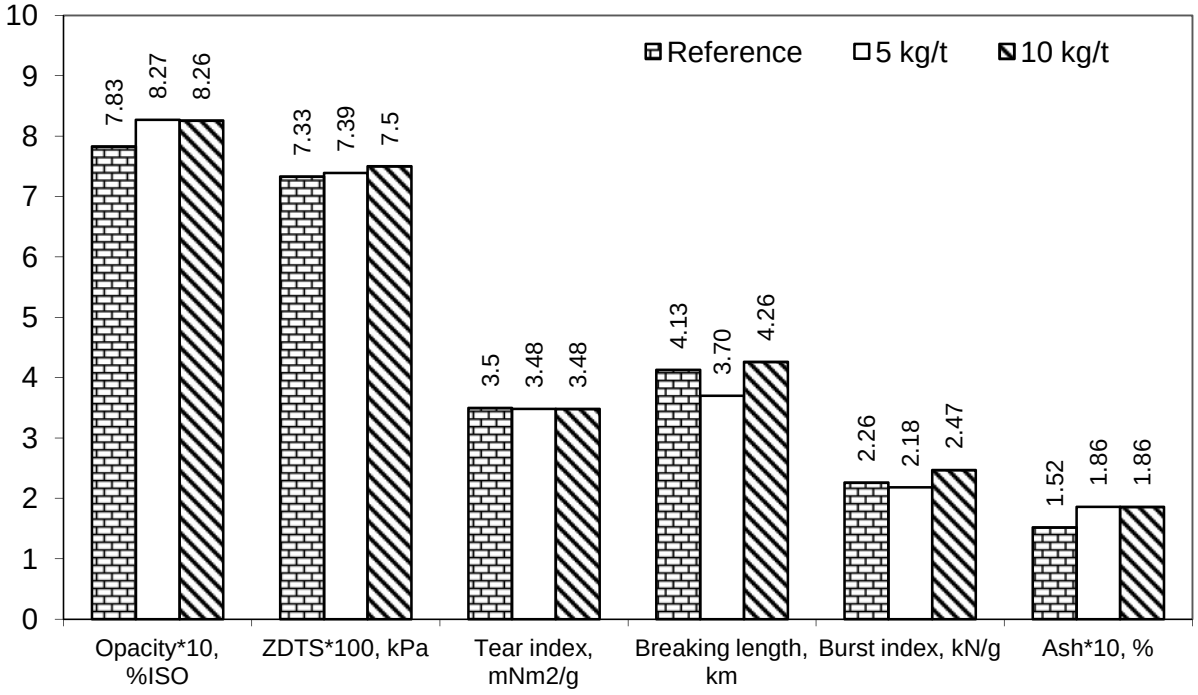

Figure 102: Effect of AS on properties of BWS pulp at 250 kg/t addition of talc

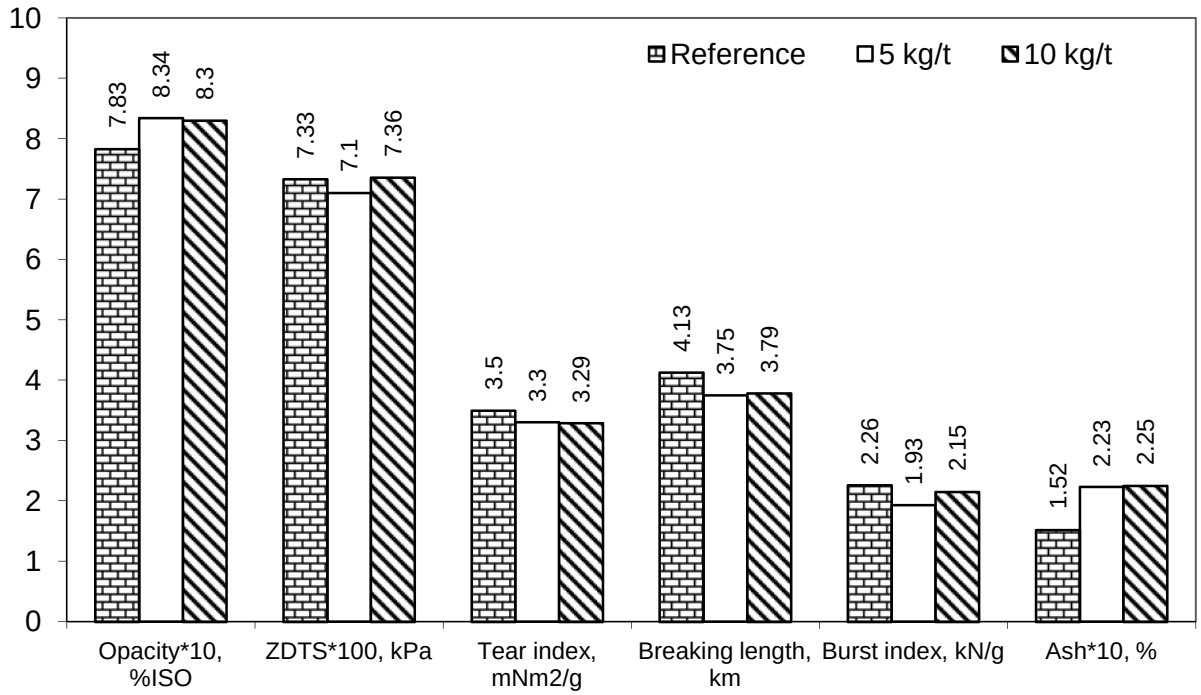

Figure 103: Effect of AS on properties of BWS pulp at 310 kg/t addition of talc

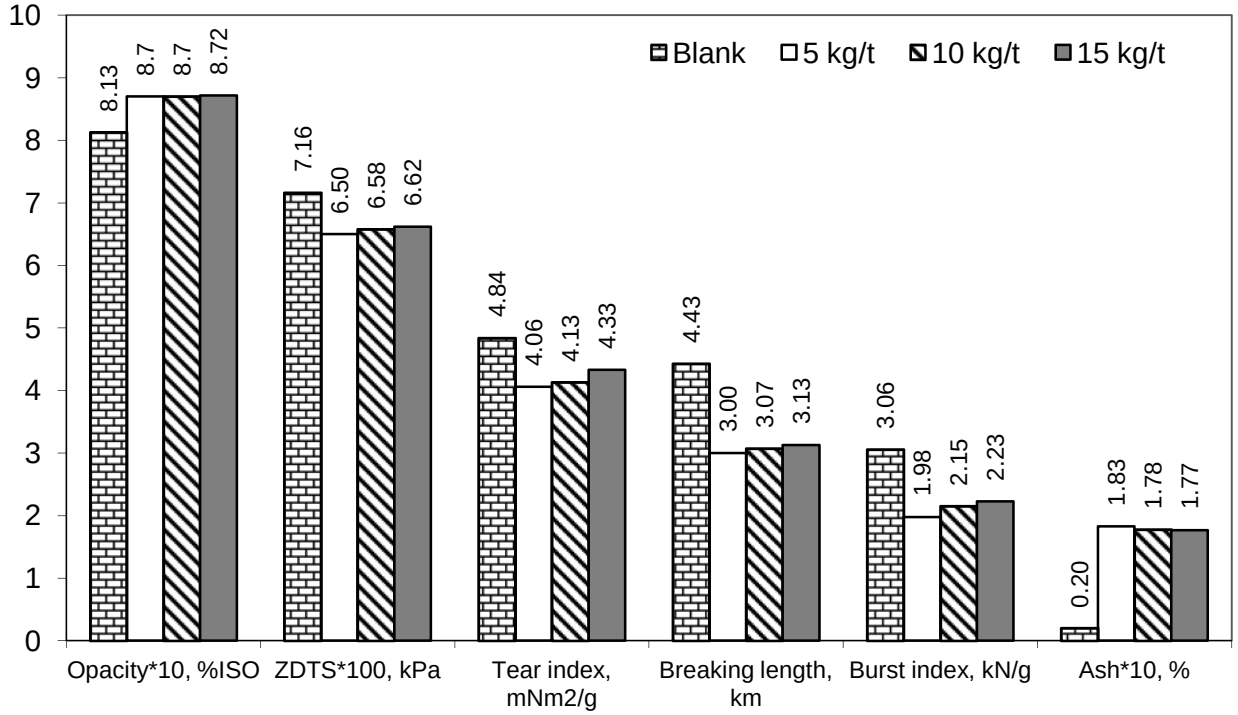

Figure 104: Effect of CS on properties of BWS pulp at 290 kg/t addition of GCC

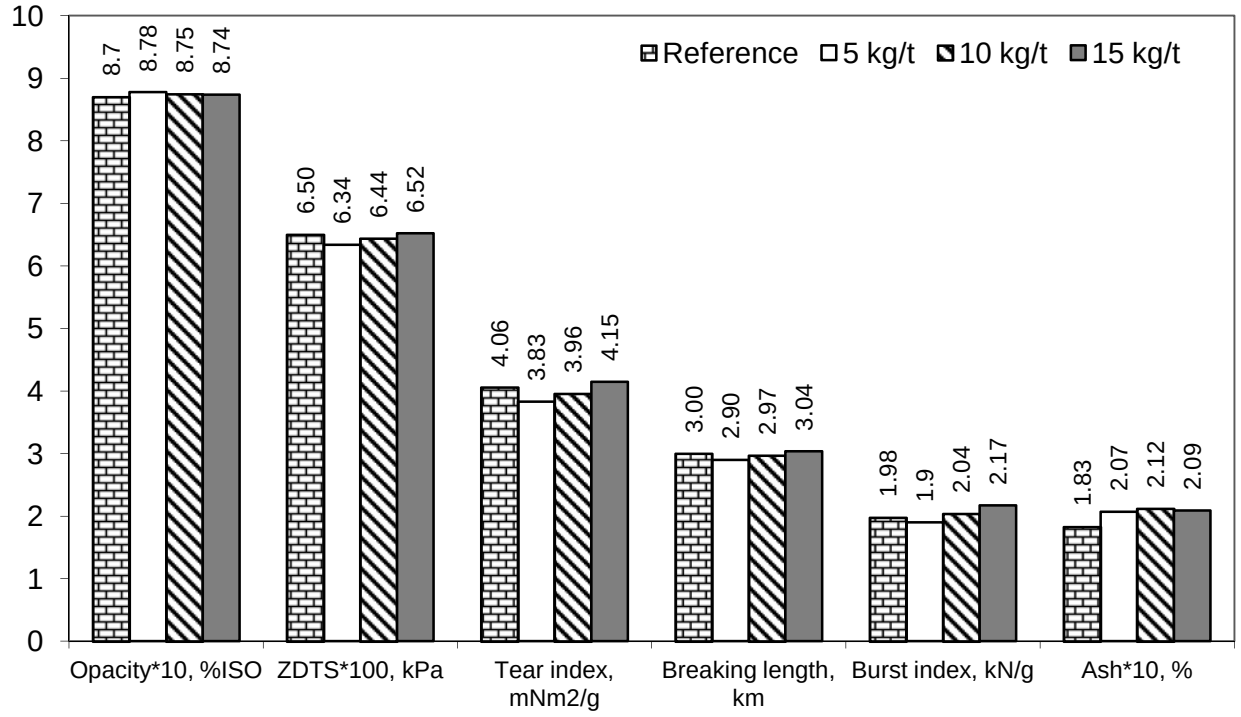

Figure 105: Effect of CS on properties of BWS pulp at 350 kg/t addition of GCC

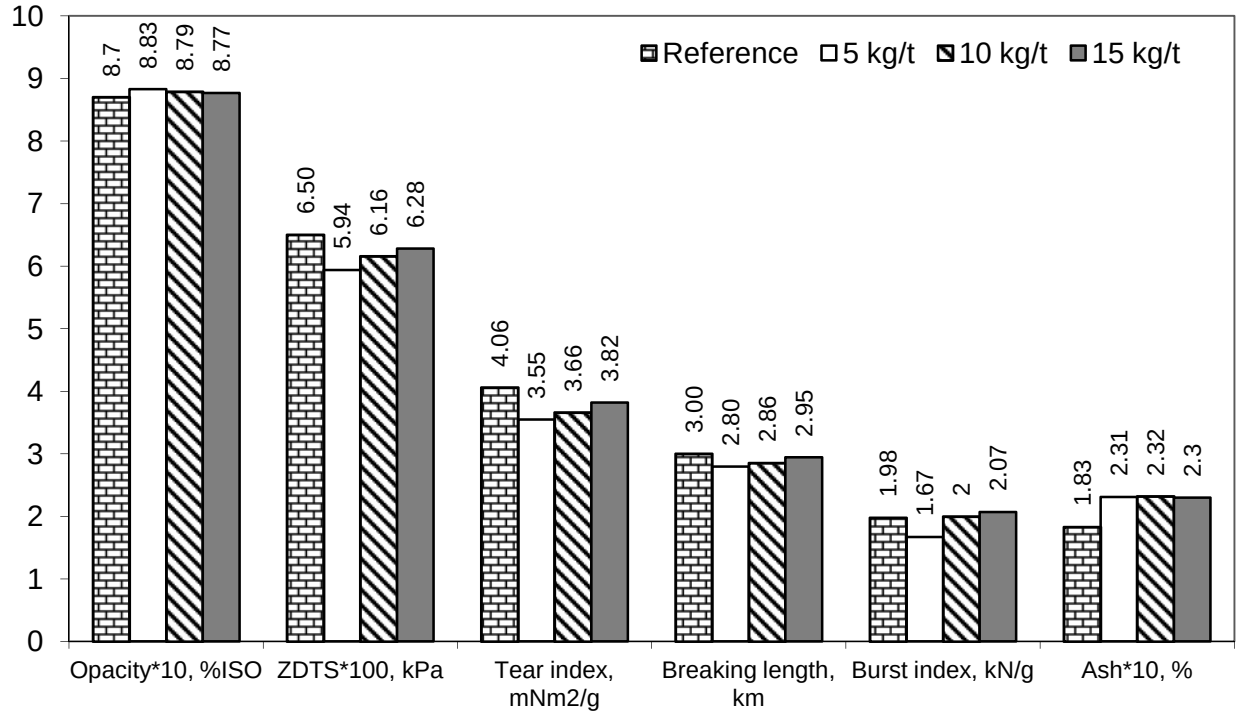

Figure 106: Effect of CS on properties of BWS pulp at 400 kg/t addition of GCC

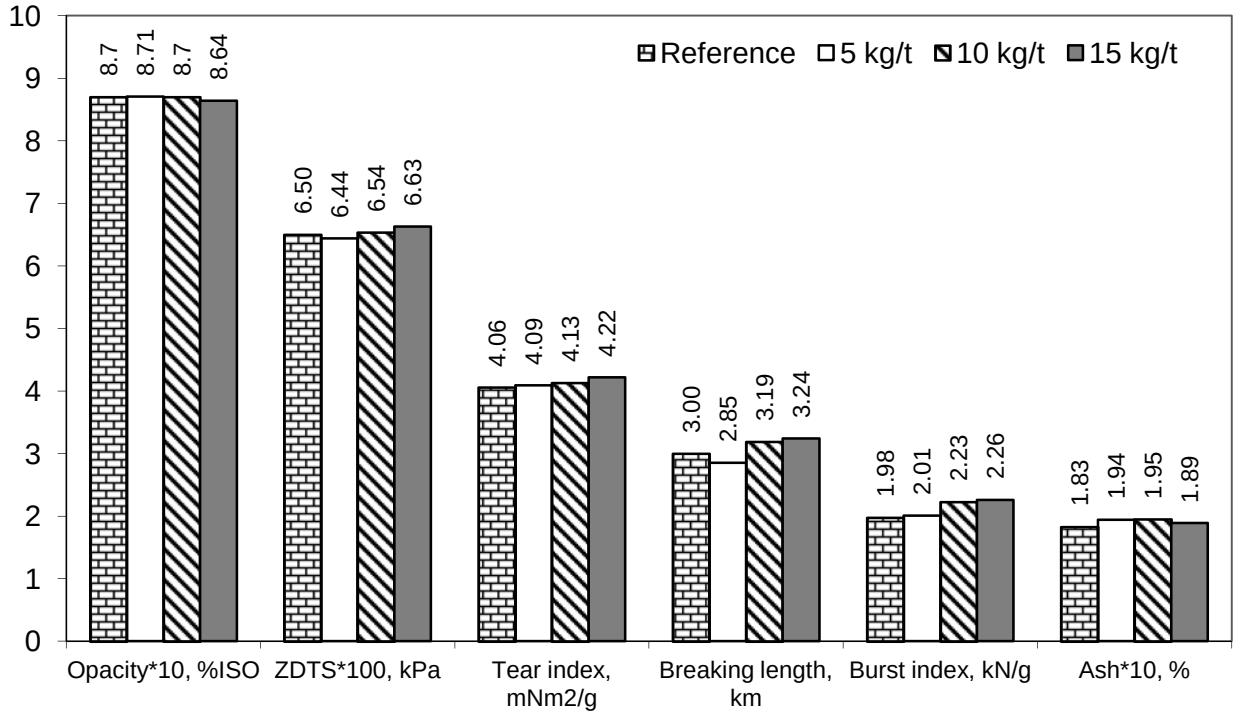

Figure 107: Effect of AS on properties of BWS pulp at 290 kg/t addition of GCC

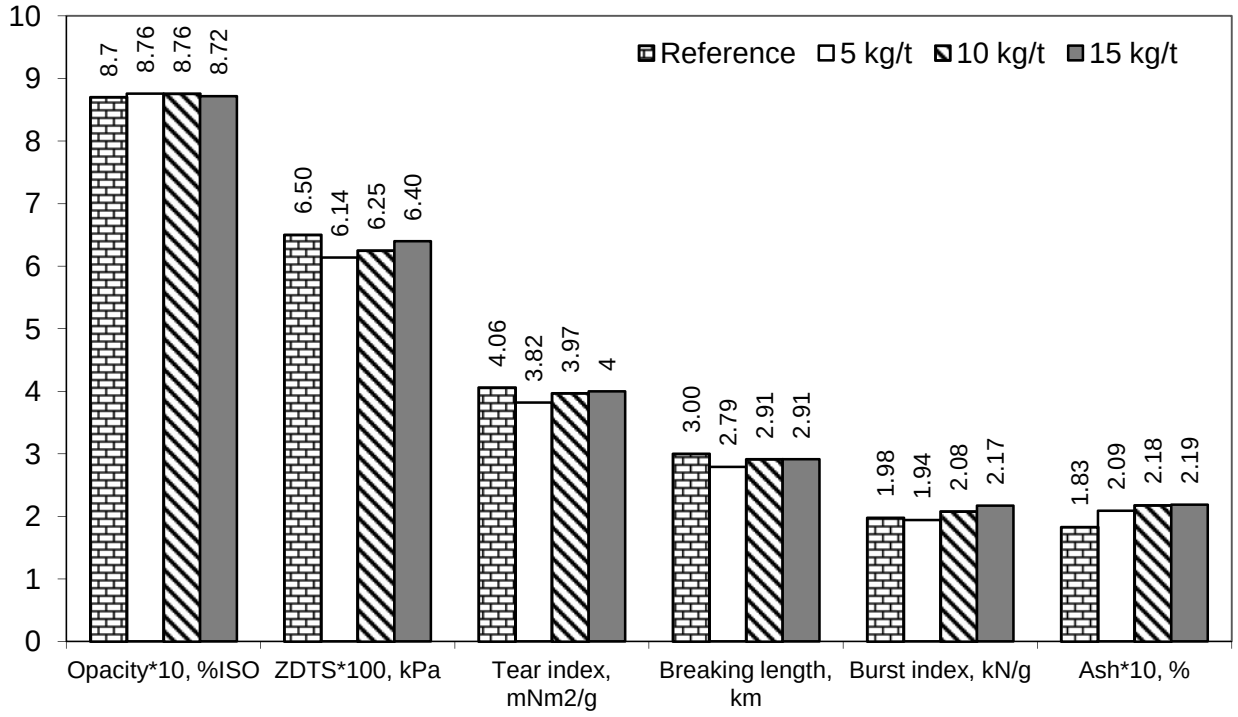

Figure 108: Effect of AS on properties of BWS pulp at 350 kg/t addition of GCC

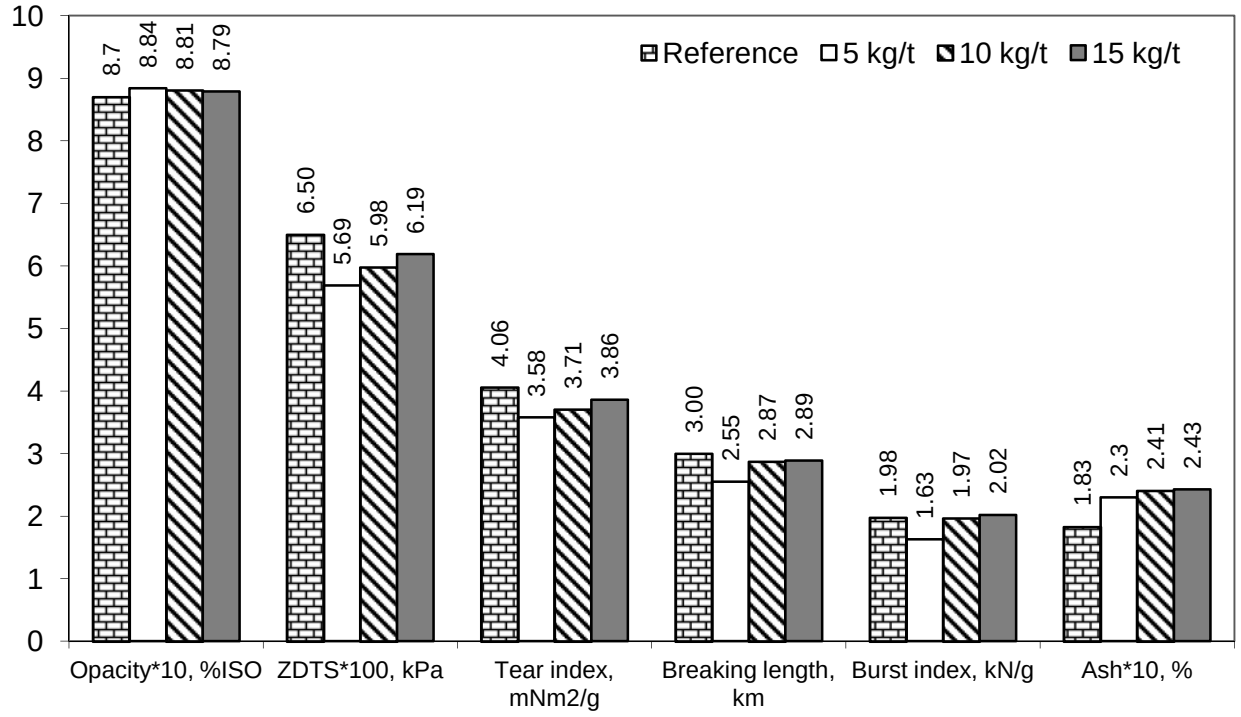

Figure 109: Effect of AS on properties of BWS pulp at 400 kg/t addition of GCC

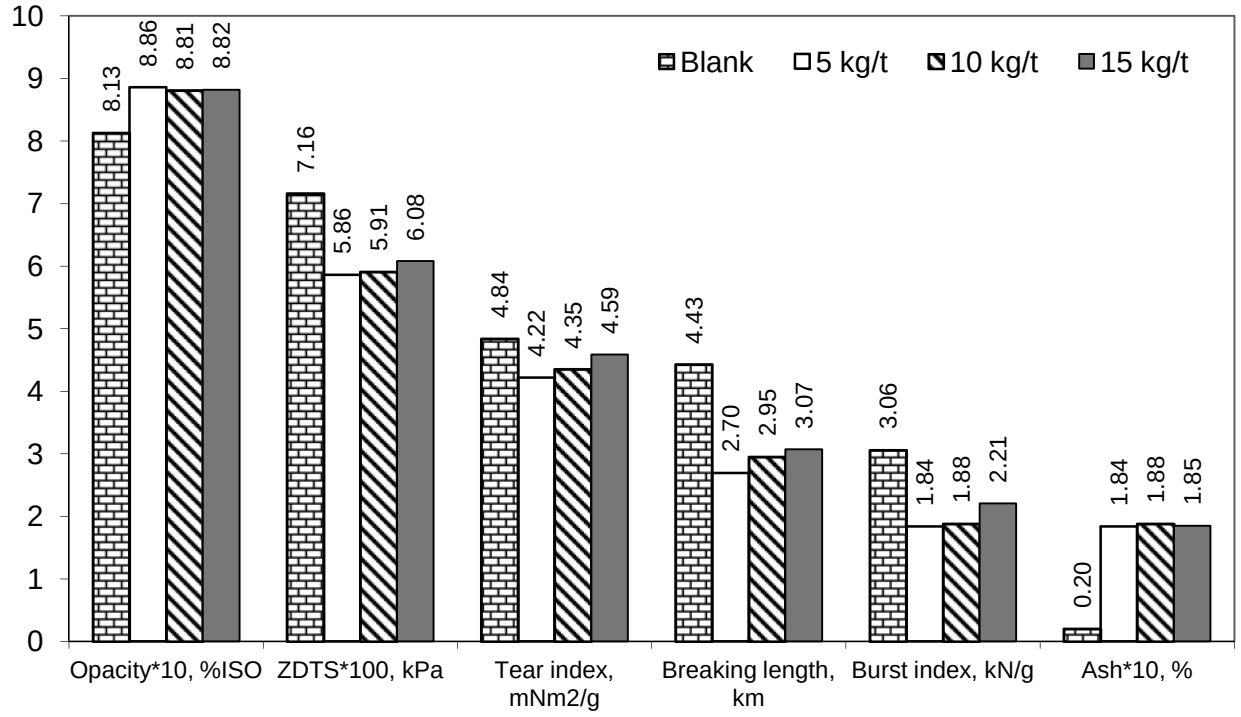

Figure 110: Effect of CS on properties of BWS pulp at 290 kg/t addition of PCC

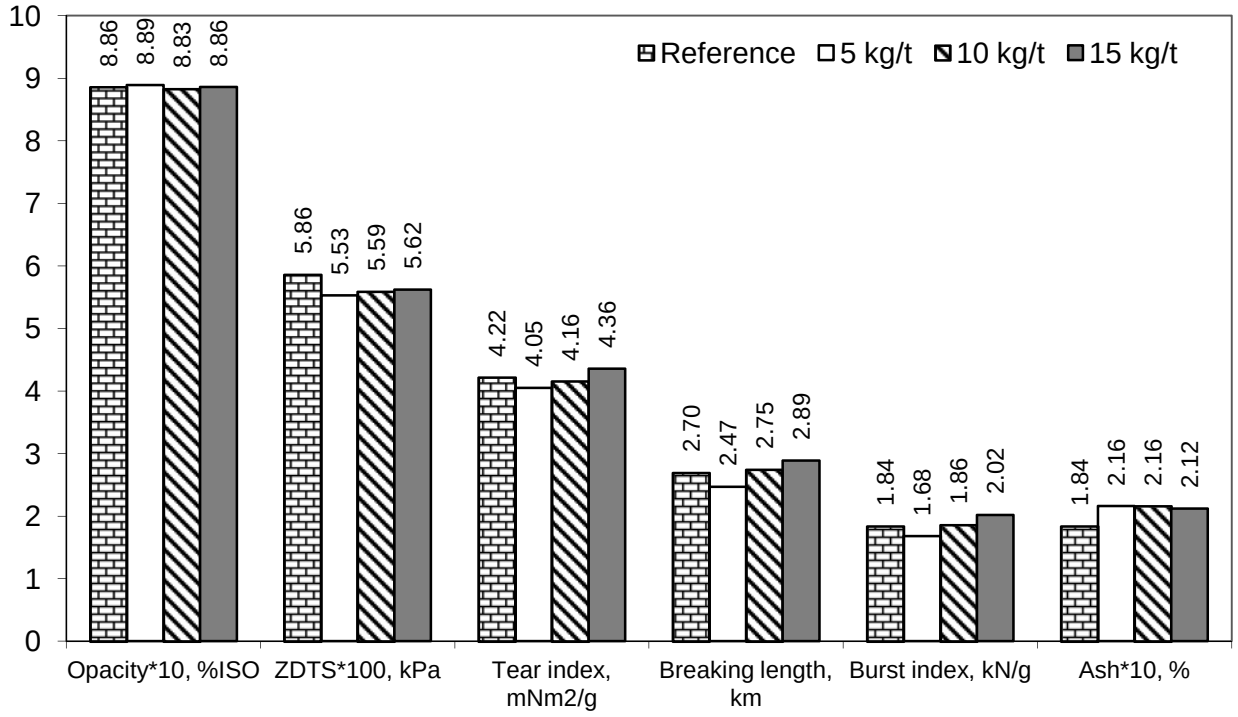

Figure 111: Effect of CS on properties of BWS pulp at 370 kg/t addition of PCC

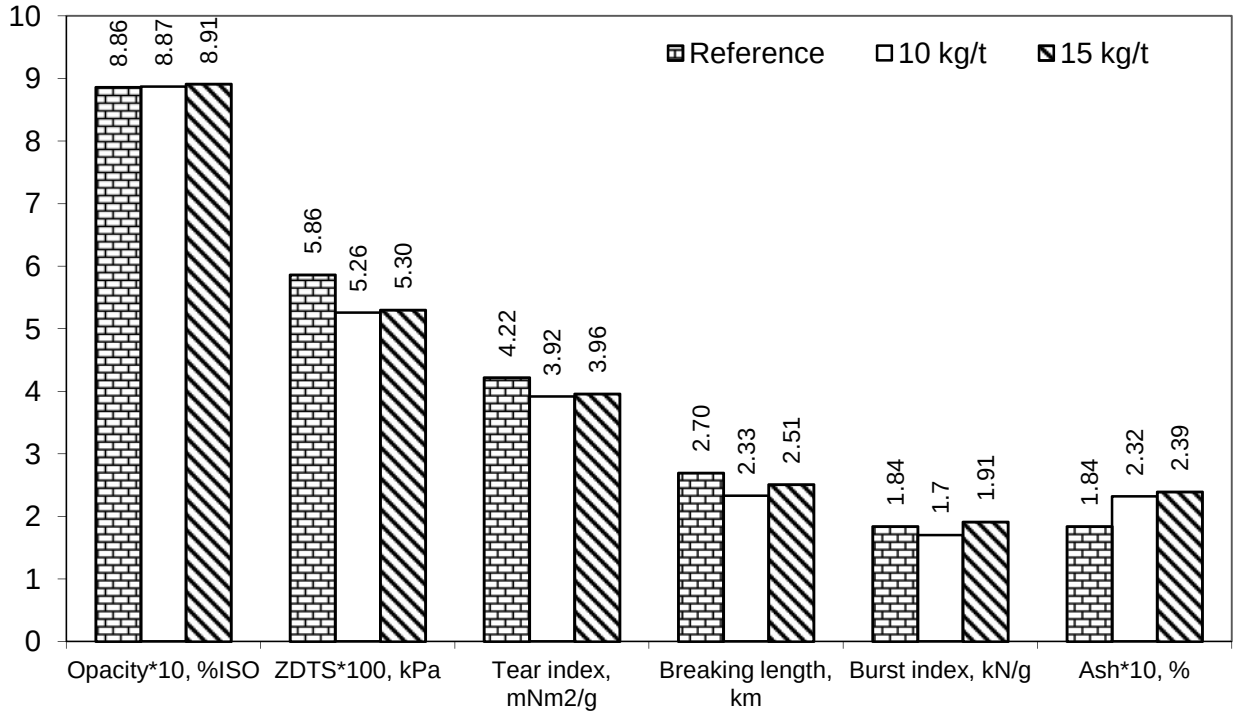

Figure 112: Effect of CS on properties of BWS pulp at 420 kg/t addition of PCC

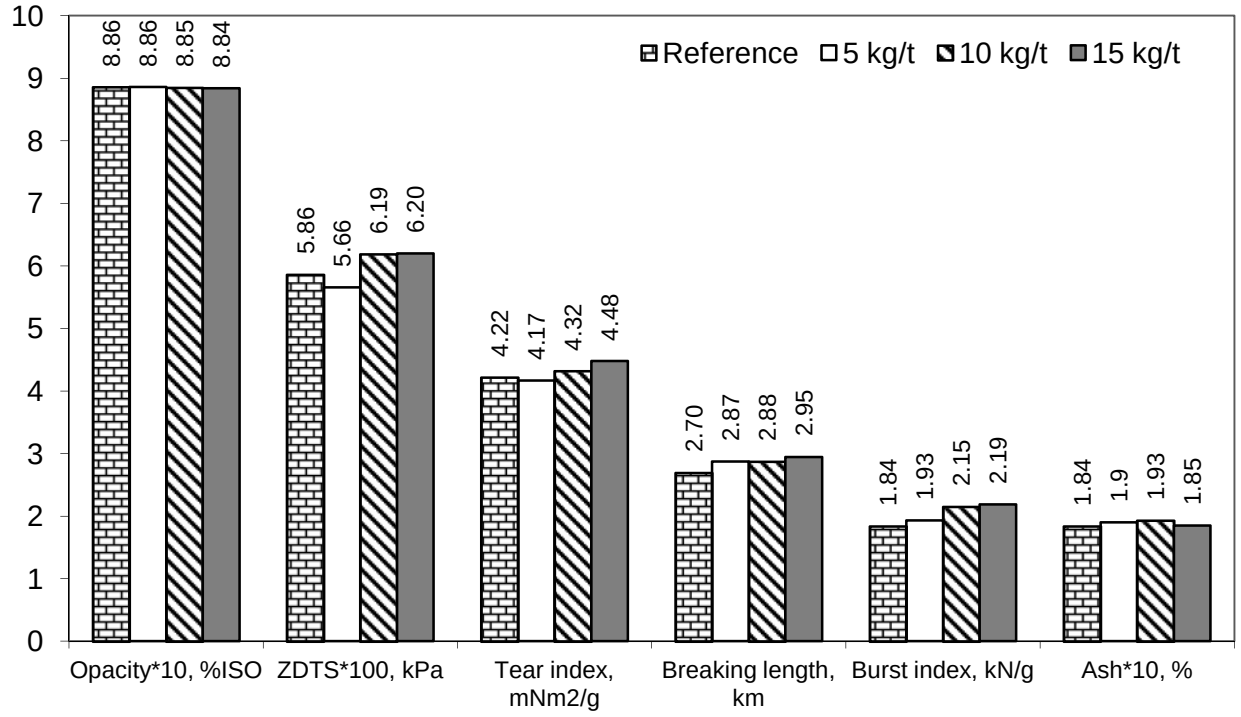

Figure 113: Effect of AS on properties of BWS pulp at 290 kg/t addition of PCC

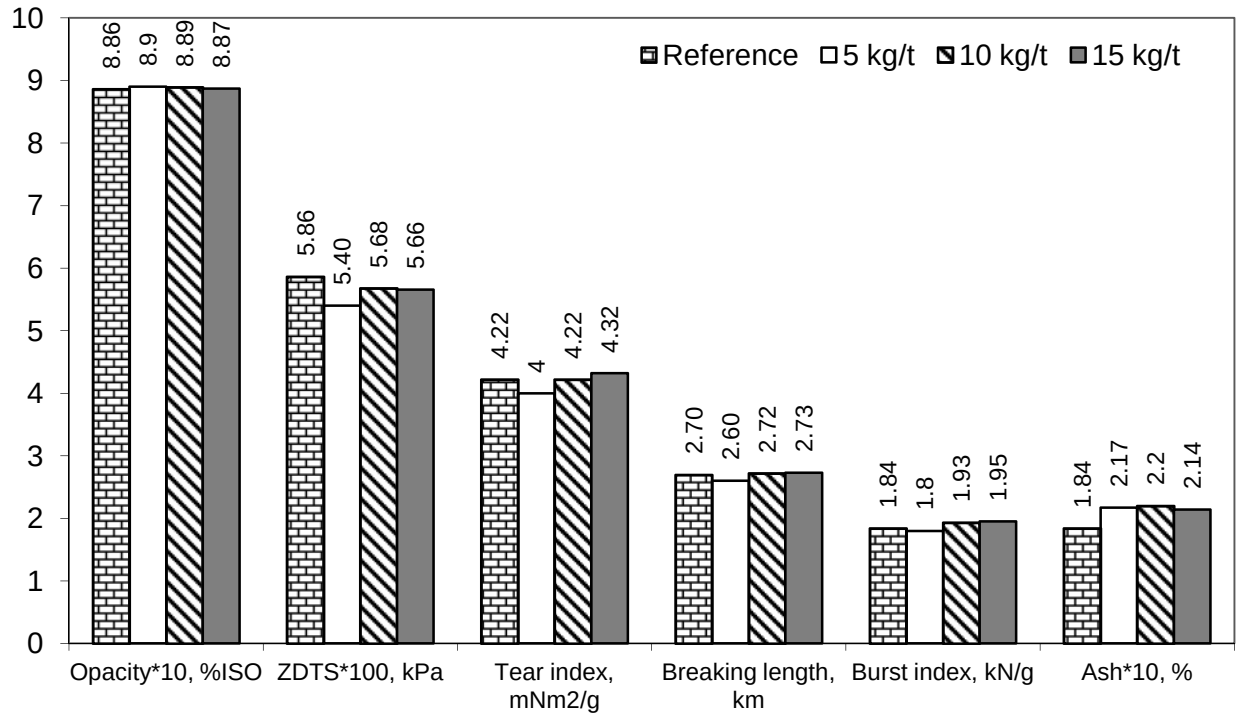

Figure 114: Effect of AS on properties of BWS pulp at 370 kg/t addition of PCC

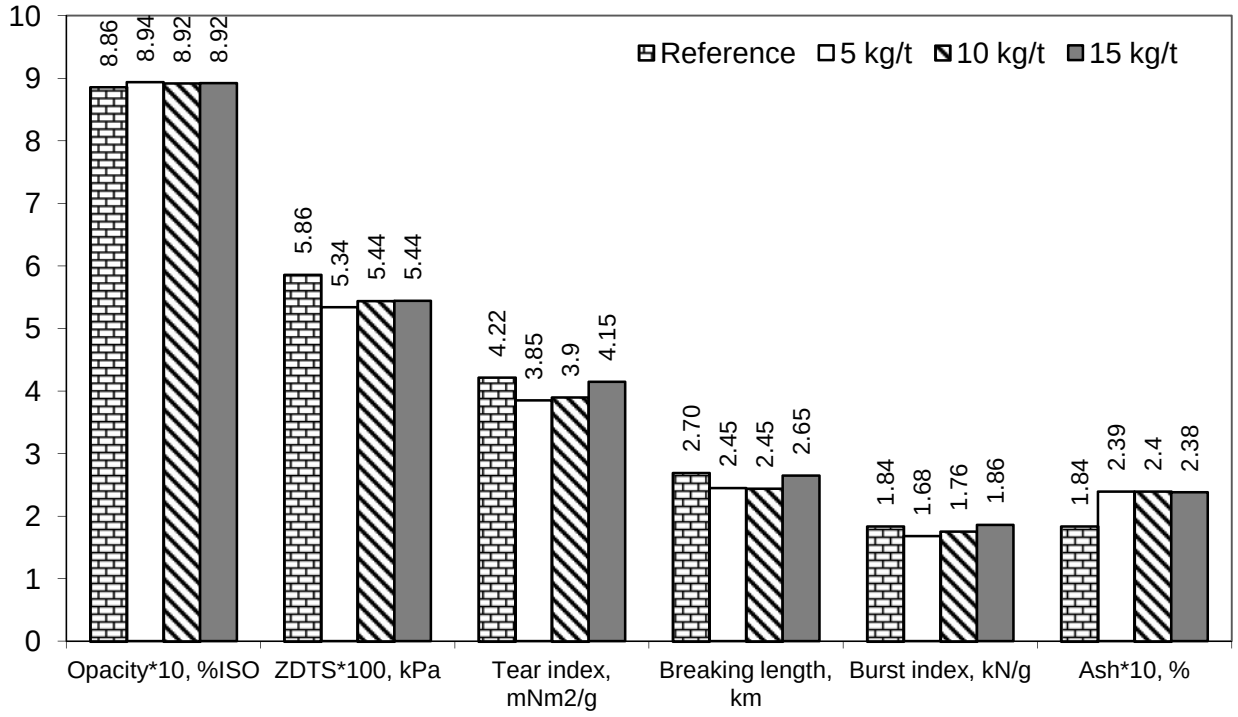

Figure 115: Effect of AS on properties of BWS pulp at 420 kg/t addition of PCC

CHAPTER – 5

Bleached Recycled (BRC) Pulp

RESULTS & DISCUSSION

5.1. Effect of cationic strength additive and talc filler on paper properties

Similar to other pulp furnishes, in case of bleached recycled (BRC) pulp also the paper strength decreased while optical properties of paper increased on increasing ash in paper. The strength properties viz., breaking length and burst index in case of BRC pulp were too low even in case of without filler (blank). Several pulp samples from different mills were procured and evaluated but the similar trend was observed in all cases. It seems that the mills are making paper from the BRC using some proportion of long fibers. The paper strength may be increased depending upon requirement through addition of either softwood or hardwood fibers in the BRC pulp, similar to case of BWS pulp. The results of effect of increasing ash in paper at different dose levels of cationic strength additive (CS) are shown in Table 108-110.

5.1.1. At 180 kg/t of talc

At 180 kg/t dose of talc, the ash content in sheets was 15% at all doses of CS. There was an increase in physical properties of paper with increase in CS dose. The opacity was comparable at all doses of CS (Figure 116).

5.1.2. At 270 kg/t of talc

At 270 kg/t addition of talc, the ash in sheets was ~18.8% at all doses of CS. At 10-15 kg/t dose of CS, all strength properties were either comparable or higher than those of reference (15% ash with 5 kg/t dose of CS). From Figure 117 it was seen for talc as filler that ash in paper can be increased from 15 to 18% using 10 kg/t dose of CS without affecting the strength properties.

5.1.3. At 330 kg/t of talc

As shown in Figure 118, at 330 kg/t addition of talc, the ash in sheets was ~21.5% at all doses of CS. In case of BRC pulp and talc filler, the ash could be increased from 15 to 21.5% using 15 kg/t dose of CS without adversely affecting the paper strength. The gain in opacity due to increased ash was around 1.3 points.

5.1.4. At 420 kg/t of talc

Increasing dose of talc to 420 kg/t increased the ash in paper to ~24%. At this ash level, all strength properties except ZDTS were lower than those of reference (Figure 119). It was not possible to increase the ash in paper to this level.

5.2. Effect of amphoteric strength additive and talc filler on paper properties

Similar to the results of CS, in case of amphoteric strength additive (AS) also, the strength properties were decreased with increasing ash in paper. Optical properties were increased at all doses of AS (Table 111-113).

5.2.1. At 180 kg/t of talc

At this talc addition level, the ash in paper was ~15%; similar to the case of CS. At this ash level, the strength properties of the sheets with both 5 kg/t dose of CS or AS were more or less comparable; the latter gave slightly higher values. With increase in dose of AS, all strength properties were increased slightly (Figure 120).

5.2.2. At 270 kg/t of talc

At 270 kg/t addition of talc, the ash in sheets was ~18.4% with all doses of AS. As shown in Figure 121, 10 kg/t dose of AS could be helpful to increase the ash in paper from 15 (reference) to 18.4% without adversely affecting the physical properties of paper.

5.2.3. At 330 kg/t of talc

The ash in sheets increased to 21.3-21.7% with increasing dose of talc to 330 kg/t. The ash in paper could be increased from 15 (reference) to ~21.5% (6.5 points) using 15 kg/t dose of AS without adversely affecting the paper strength and improving the optical properties of paper (Figure 122).

5.2.4. At 420 kg/t of talc

Increasing dose of talc to 420 kg/t increased the ash in paper to ~25% (1 point higher than that with CS). At this ash level also, all strength properties except breaking length were comparable than those of reference when 15 kg/t dose of AS was used. The gain in opacity was also 1 point (Figure 123).

5.3. Effect of cationic strength additive and GCC filler on paper properties

The different doses of CS were used at all four ash levels and the results are shown in Table 114-116. The FPAR of GCC filler was comparatively lower than that of talc filler.

5.3.1. At 250 kg/t of GCC

At this addition level of GCC, the ash in paper was ~15% at all doses of CS. There was an increase in all the strength properties with increase in CS dose. Opacity was almost comparable at all CS doses (Figure 124).

5.3.2. At 300 kg/t of GCC

At 300 kg/t addition of GCC, the ash in paper was ~18-18.5% at all doses of CS. With 5-10 kg/t dose of CS, the strength properties were comparable to those of reference (15% ash with 5 kg/t dose of CS) (Figure 125). The ash in paper could be increased from 15 to 18% using 5 kg extra dose of CS without affecting the strength properties of paper.

5.3.3. At 360 kg/t of GCC

At this addition level of GCC, the ash in paper was ~20.6% at all doses of CS. With 10-15 kg/t dose of CS, all strength properties were comparable to those of reference (Figure 126).

5.3.4. At 420 kg/t of GCC

At this addition level of GCC, the ash in paper was ~24.5% at all doses of CS. The ash in paper could be increased from 15% to 24.5% using 15 kg/t dose of CS without much affecting the physical properties of paper and little gain in optical properties (Figure 127).

5.4. Effect of amphoteric strength additive and GCC filler on paper properties

The effect of different doses of AS with increasing GCC filler level in paper on various process and paper properties is shown in Table 117-119.

5.4.1. At 250 kg/t of GCC

At this GCC addition level, the ash in paper was ~16% at all doses of AS; slightly higher than that with CS. The 5 kg/t dose of AS gave comparable paper properties to 5 kg/t dose of CS. There was an increase in all the strength properties with increase in AS dose (Figure 128).

5.4.2. At 300 kg/t of GCC

At 300 kg/t addition of GCC, the ash in paper was ~19-20.4% at all doses of AS. This much ash could be increased using 5 kg/t dose of AS without adversely affecting the paper properties except tear index which was decreased by 16% as compared with reference. At 10 kg/t dose of AS, all paper properties were either comparable or higher than those of reference (Figure 129).

5.4.3. At 360 kg/t of GCC

At this GCC addition level, the ash in paper was around 22% at all doses of AS. At 10 kg/t dose of AS, all physical properties of paper were either comparable or higher than those of reference. On increasing the dose of AS to 15 kg/t, all paper properties were increased (Figure 130).

5.4.4. At 420 kg/t of GCC

At this GCC addition level, the ash in paper was around 24%. At 15 kg/t dose of AS, all physical properties of paper were comparable to those of reference. The ash in paper could be increased from 15 to 24% using 15 kg/t dose of AS without adversely affecting the paper strength and enhancing the optical properties of paper (Figure 131).

5.5. Effect of cationic strength additive and PCC filler on paper properties

The bulk of paper with PCC was comparatively higher than that with talc and GCC. Optical properties viz. brightness, whiteness, opacity, and scattering coefficient increased significantly with PCC as compared to those with talc (Table 120-122).

5.5.1. At 220 kg/t of PCC

At 220 kg/t addition of PCC, the ash in paper at all doses of CS was ~15%. As expected, the physical properties of paper increased on increasing dose of CS (Figure 132).

5.5.2. At 280 kg/t of PCC

At 280 kg/t addition of PCC, the ash in paper was approximately 18.5%. At this ash level, all strength properties of paper using 5-10 kg/t dose of CS were more or less comparable to those of reference (15% ash with PCC and 5 kg/t dose of CS). On increasing dose of CS to15 kg/t, the strength properties were further increased (Figure 133).

5.5.3. At 360 kg/t of PCC

At this PCC addition level, the ash in paper was ~21%. The ash in paper could be increased from 15% (reference) to 21% using 15 kg/t dose of CS without adversely affecting the paper properties (Figure 112).

5.5.4. At 450 kg/t of GCC

At this PCC addition level, the ash in paper was around 24%. At this ash level all paper properties were lower than those of reference even with the use of highest dose of CS (Figure 135).

5. 6. Effect of amphoteric strength additive and PCC filler on paper properties

The effect of different doses of AS with increasing PCC filler level in paper on various process and paper properties is shown in Table 123-125.

5.6.1. At 220 kg/t of PCC

At 220 kg/t addition of PCC, the ash in paper at all doses of CS was 15-16%; it was higher with higher dose of AS. The paper properties were comparable with 5 kg/t dose of AS to those of reference and increased on increasing dose of AS (Figure 136).

5.6.2. At 280 kg/t of PCC

At 280 kg/t addition of PCC, the ash in paper was approximately 18.5%. This much ash could be increased using 5 kg/t dose of AS without adversely affecting the paper properties except tear index which was decreased by 11.6% as compared with reference. At 10 kg/t dose of AS, all paper properties were much higher than those of reference except tear index which was comparable (Figure 137).

5.6.3. At 360 kg/t of PCC

At this PCC addition level, the ash in paper was ~21.6%. At this ash level, most of the strength properties with the usage of 10 kg/t dose of AS were comparable to those of reference. The drop in tear index was 3.3%. This showed that the AS was more effective on increasing the ash in paper with less compromise in paper strength than CS (Figure 138).

5.6.4. At 450 kg/t of PCC

At this PCC addition level, the ash in paper was around 24.8%. At 15 kg/t dose of AS, the burst index and ZDTS were either comparable or higher than those of reference whereas little drop in breaking length (7.9%) and tear index (2.8%) was observed (Figure 139).

In case of BRC pulp and PCC filler, the ash in paper could be increased from 15% (reference) to ~22% using 10-15 kg/t dose of AS without affecting the paper strength.

Table 108: Properties of BRC pulp with talc and cationic strength additive at 5 kg/t

Talc addition, %	Blank*	18	27	33	42
Retained ash, %	1.7	14.8	18.8	21.8	23.7
FPAR, %	-	85.9	80.4	81.0	74.4
CSF	427	450	499	493	475
Streaming potential, mV	-387	-155	-187	-172	-178
Charge demand, µeq/l	23.1	11.2	12.3	12.9	13.2
Zeta potential, mV	-20.7	-16.7	-15.0	-14.6	-12.7
Conductivity, mS	0.467	0.467	0.463	0.471	0.465
Bulk, cc/g	1.56	1.51	1.47	1.46	1.47
Breaking length, m	2186	1919	1680	1589	1262
Burst index, kN/g	1.65	1.26	1.21	1.13	0.99
Tear index, mNm^2/g	7.57	5.61	5.22	5.00	5.01
Bending stiffness, mNm	0.141	0.113	0.102	0.093	0.086
Double fold, no.	8	5	5	4	3
Wax pick no.	8	6	4	3	3
ZD tensile strength, kPa	438	489	453	451	417
Air permeance, Gurley s	6.2	4.0	5.1	5.5	6.1
Bendtsen roughness, ml/min	217	204	200	189	192
Brightness, %ISO	89.3	86.8	86.7	87.4	88.0
Opacity, %ISO	82.4	86.2	86.4	86.5	87.3
Scattering coefficient, m^2/kg	37.9	42.7	43.3	44.2	45.9
CIE whiteness	122.5	115.6	116.4	116.6	116.9
Yellowness	-13.98	-12.53	-12.06	-11.96	-12.09
L*	94.9	93.9	93.8	93.8	94.4
a*	2.19	1.98	1.94	1.93	1.95
b*	-6.12	-6.95	-6.71	-6.66	-6.76

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 5 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Blank: Unbeaten BRC pulp without addition of wet-end chemicals*

Table 109: Properties of BRC pulp with talc and cationic strength additive at 10 kg/t

Talc addition, %	Reference*	18	27	33	42
Retained ash, %	14.8	14.8	18.7	21.3	24.2
FPAR, %	85.9	85.9	80.0	79.0	76.1
CSF	450	475	482	500	525
Streaming potential, mV	-155	-130	-156	-162	-171
Charge demand, µeq/l	11.2	11.7	12.4	12.9	13.8
Zeta potential, mV	-16.7	-15.9	-15.2	-14.7	-13.1
Conductivity, mS	0.467	0.455	0.449	0.422	0.397
Bulk, cc/g	1.51	1.26	1.45	1.42	1.43
Breaking length, m	1919	2012	1802	1614	1562
Burst index, kN/g	1.26	1.49	1.38	1.24	1.15
Tear index, mNm^2/g	5.61	6.95	5.78	5.67	5.16
Bending stiffness, mNm	0.113	0.114	0.111	0.109	0.103
Double fold, no.	5	6	5	5	4
Wax pick no.	6	7	6	6	6
ZD tensile strength, kPa	489	508	491	482	466
Air permeance, Gurley s	4.0	4.7	4.9	5.3	6.0
Bendtsen roughness, ml/min	204	211	192	184	203
Brightness, %ISO	86.8	86.4	86.7	87.1	87.7
Opacity, %ISO	86.2	86.7	86.9	87.1	87.4
Scattering coefficient, m^2/kg	42.7	40.0	40.8	41.4	43.3
CIE whiteness	115.6	115.5	115.7	115.9	116.3
Yellowness	-12.53	-12.32	-11.98	-12.02	-12.08
L*	93.9	93.6	93.8	93.9	94.2
a*	1.98	1.99	1.96	1.97	1.97
b*	-6.95	-6.84	-6.67	-6.70	-6.75

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 10 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BRS with talc and CS, 5 kg/t at 15% ash level*

Table 110: Properties of BRC pulp with talc and cationic strength additive at 15 kg/t

Talc addition, %	Reference*	27	33	42
Retained ash, %	14.8	18.5	21.2	24.5
FPAR, %	85.9	79.0	78.6	77.1
CSF	450	510	522	540
Streaming potential, mV	-155	-167	-178	-188
Charge demand, µeq/l	11.2	12.3	12.9	13.2
Zeta potential, mV	-16.7	-15.0	-14.6	-12.7
Conductivity, mS	0.467	0.463	0.471	0.465
Bulk, cc/g	1.51	1.44	1.42	1.42
Breaking length, m	1919	1987	1889	1623
Burst index, kN/g	1.26	1.42	1.26	1.19
Tear index, mNm^2/g	5.61	5.94	5.82	5.38
Bending stiffness, mNm	0.113	0.102	0.095	0.081
Double fold, no.	5	6	5	4
Wax pick no.	6	6	6	6
ZD tensile strength, kPa	489	522	500	494
Air permeance, Gurley s	4.0	5.4	5.5	6.2
Bendtsen roughness, ml/min	204	204	203	190
Brightness, %ISO	86.8	86.6	87.1	87.7
Opacity, %ISO	86.2	86.7	87.3	87.5
Scattering coefficient, m^2/kg	42.7	41.0	41.6	43.6
CIE whiteness	115.6	116.3	116.4	116.9
Yellowness	-12.53	-12.46	-12.45	-12.40
L*	93.9	93.6	93.8	94.1
a*	1.98	2.00	2.04	2.03
b*	-6.95	-6.99	-6.93	-6.92

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 15 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BRS with talc and CS, 5 kg/t at 15% ash level*

Table 111: Properties of BRC pulp with talc and amphoteric strength additive at 5 kg/t

Talc addition, %	Reference*	18	27	33	42
Retained ash, %	14.8	14.7	17.9	21.3	24.8
FPAR, %	85.9	85.2	76.2	79.0	78.1
CSF	450	415	410	390	388
Streaming potential, mV	-155	-99	-92	-88	-85
Charge demand, µeq/l	11.2	4.6	4.9	5.1	4.7
Zeta potential, mV	-16.7	-4.9	-5.2	-5.7	-6.2
Conductivity, mS	0.467	0.408	0.409	0.503	0.511
Bulk, cc/g	1.51	1.49	1.47	1.46	1.45
Breaking length, m	1919	1732	1538	1415	1313
Burst index, kN/g	1.26	1.35	1.23	1.17	1.01
Tear index, mNm^2/g	5.61	5.84	5.61	5.21	5.17
Bending stiffness, mNm	0.113	0.103	0.102	0.100	0.089
Double fold, no.	5	5	4	4	3
Wax pick no.	6	6	4	3	3
ZD tensile strength, kPa	489	489	473	456	451
Air permeance, Gurley s	4.0	4.3	4.5	4.7	5.2
Bendtsen roughness, ml/min	204	244	212	207	205
Brightness, %ISO	86.8	87.0	87.6	87.8	87.9
Opacity, %ISO	86.2	85.5	85.7	87.0	87.3
Scattering coefficient, m^2/kg	42.7	42.5	43.3	44.8	45.4
CIE whiteness	115.6	115.8	116.4	116.6	116.8
Yellowness	-12.53	-12.35	-12.34	-12.07	-9.75
L*	93.9	93.9	94.2	94.1	93.6
a*	1.98	2.00	2.02	1.97	1.91
b*	-6.95	-6.88	-6.89	-6.74	-5.57

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 5 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BRS with talc and CS, 5 kg/t at 15% ash level*

Table 112: Properties of BRC pulp with talc and amphoteric strength additive at 10 kg/t

Talc addition, %	Reference*	18	27	33	42
Retained ash, %	14.8	15.2	18.4	21.3	24.8
FPAR, %	85.9	88.5	78.6	79.0	78.1
CSF	450	419	414	395	390
Streaming potential, mV	-155	-91	-88	-81	75
Charge demand, µeq/l	11.2	5.1	5.7	5.9	6.2
Zeta potential, mV	-16.7	-5.4	-5.7	-6.6	-7.2
Conductivity, mS	0.467	0.401	0.398	0.498	0.485
Bulk, cc/g	1.51	1.49	1.45	1.43	1.42
Breaking length, m	1919	1964	1843	1801	1543
Burst index, kN/g	1.26	1.67	1.53	1.44	1.27
Tear index, mNm^2/g	5.61	6.30	6.07	5.99	5.32
Bending stiffness, mNm	0.113	0.108	0.105	0.102	0.090
Double fold, no.	5	7	6	5	4
Wax pick no.	6	2	2	2	2
ZD tensile strength, kPa	489	536	521	500	499
Air permeance, Gurley s	4.0	6.0	6.2	6.3	7.0
Bendtsen roughness, ml/min	204	230	222	195	190
Brightness, %ISO	86.8	86.9	87.2	87.5	87.6
Opacity, %ISO	86.2	86.6	87.2	87.3	87.9
Scattering coefficient, m^2/kg	42.7	41.0	42.3	43.0	45.3
CIE whiteness	115.6	115.7	115.9	116.3	116.6
Yellowness	-12.53	-10.51	-10.41	-10.19	-10.03
L*	93.9	92.8	93.0	93.1	93.2
a*	1.98	1.89	1.88	1.90	1.90
b*	-6.95	-5.90	-5.86	-5.76	-5.69

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 10 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BRS with talc and CS, 5 kg/t at 15% ash level*

Table 113: Properties of BRC pulp with talc and amphoteric strength additive at 15 kg/t

Talc addition, %	Reference*	18	27	33	42
Retained ash, %	14.8	15.3	18.4	21.7	25.2
FPAR, %	85.9	89.2	78.6	80.6	79.5
CSF	450	421	419	401	395
Streaming potential, mV	-155	-95	-88	-82	-71
Charge demand, µeq/l	11.2	6.1	6.4	6.9	7.2
Zeta potential, mV	-16.7	-5.9	-6.7	-6.9	-7.1
Conductivity, mS	0.467	0.409	0.389	0.356	0.415
Bulk, cc/g	1.51	1.47	1.45	1.44	1.43
Breaking length, m	1919	2232	1902	1829	1693
Burst index, kN/g	1.26	1.83	1.55	1.47	1.30
Tear index, mNm^2/g	5.61	6.38	6.14	6.09	5.74
Bending stiffness, mNm	0.113	0.111	0.106	0.104	0.091
Double fold, no.	5	9	7	5	5
Wax pick no.	6	7	6	6	3
ZD tensile strength, kPa	489	576	549	507	504
Air permeance, Gurley s	4.0	5.8	5.9	6.8	7.6
Bendtsen roughness, ml/min	204	223	198	190	183
Brightness, %ISO	86.8	87.9	87.3	87.4	87.7
Opacity, %ISO	86.2	86.7	86.9	87.0	87.2
Scattering coefficient, m^2/kg	42.7	40.9	42.2	43.4	44.7
CIE whiteness	115.6	116.4	116.6	117.0	117.2
Yellowness	-12.53	-10.77	-10.50	-10.44	-10.38
L*	93.9	92.8	93.0	93.2	93.5
a*	1.98	1.96	1.91	1.91	1.89
b*	-6.95	-6.05	-5.91	-5.89	-5.87

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 15 kg/t + AKD + Talc – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BRS with talc and CS, 5 kg/t at 15% ash level*

Table 114: Properties of BRC pulp with GCC and cationic strength additive at 5 kg/t

GCC addition, %	Blank*	25	30	36	42
Retained ash, %	1.7	15.5	18.4	20.6	24.3
FPAR, %	-	69.0	72.4	71.4	76.4
Streaming potential, mV	-387	-220	-223	-236	-242
Charge demand, µeq/l	23.1	6.4	6.9	7.7	8.2
Zeta potential, mV	-20.7	-15.4	-15.2	-14.2	-13.0
Conductivity, mS	0.467	0.477	0.466	0.459	0.450
Bulk, cc/g	1.56	1.50	1.49	1.48	1.47
Breaking length, m	2186	1571	1508	1464	1216
Burst index, kN/g	1.65	1.24	1.17	1.05	0.91
Tear index, mNm^2/g	7.57	6.17	6.08	5.34	4.86
Bending stiffness, mNm	0.141	0.098	0.095	0.086	0.081
Double fold, no.	8	4	3	3	2
Wax pick no.	8	4	0	2	0
ZD tensile strength, kPa	438	437	462	430	452
Air permeance, Gurley s	6.2	4.9	5.1	5.5	5.8
Bendtsen roughness, ml/min	217	194	216	204	199
Brightness, %ISO	89.3	87.5	88.1	88.8	89.0
Opacity, %ISO	82.4	88.8	89.0	89.5	90.2
Scattering coefficient, m^2/kg	37.9	51.7	52.0	55.1	58.4
CIE whiteness	122.5	113.0	113.4	113.7	113.9
Yellowness	-13.98	-12.64	-11.01	-10.59	-10.77
L*	94.9	94.6	94.1	94.3	94.5
a*	2.19	1.98	1.93	1.79	1.82
b*	-6.12	-7.04	-6.21	-5.97	-6.07

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 5 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Blank: Unbeaten BRC pulp without addition of wet-end chemicals*

Table 115: Properties of BRC pulp with GCC and cationic strength additive at 10 kg/t

GCC addition, %	Reference*	25	30	36	42
Retained ash, %	15.5	14.8	18.0	20.6	24.5
FPAR, %	69.0	65.5	70.6	71.4	77.1
Streaming potential, mV	-220	-220	222	229	232
Charge demand, µeq/l	6.4	6.9	7.2	7.7	8.4
Zeta potential, mV	-15.4	-15.4	-15.2	-14.2	-13.0
Conductivity, mS	0.477	0.479	0.459	0.451	0.440
Bulk, cc/g	1.50	1.49	1.47	1.46	1.46
Breaking length, m	1571	1743	1681	1621	1522
Burst index, kN/g	1.24	1.47	1.23	1.18	1.14
Tear index, mNm^2/g	6.17	6.21	6.15	5.55	5.61
Bending stiffness, mNm	0.098	0.109	0.097	0.088	0.084
Double fold, no.	4	4	3	3	3
Wax pick no.	4	6	4	3	2
ZD tensile strength, kPa	437	484	482	469	471
Air permeance, Gurley s	4.9	4.9	5.4	5.6	5.8
Bendtsen roughness, ml/min	194	220	208	205	197
Brightness, %ISO	87.5	87.3	87.7	88.2	89.1
Opacity, %ISO	88.8	88.2	88.6	88.9	89.1
Scattering coefficient, m^2/kg	51.7	49.9	51.0	52.9	55.0
CIE whiteness	113.0	113.6	113.8	114.7	114.9
Yellowness	-12.64	-11.32	-11.02	-11.30	-11.36
L*	94.6	93.9	94.1	94.3	94.5
a*	1.98	1.94	1.90	1.92	1.92
b*	-7.04	-6.36	-6.21	-6.36	-6.40

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 10 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BRS with GCC and CS, 5 kg/t at 15% ash level*

Table 116: Properties of BRC pulp with GCC and cationic strength additive at 15 kg/t

GCC addition, %	Reference*	25	30	36	42
Retained ash, %	15.5	15.2	18.5	20.7	24.8
FPAR, %	69.0	67.5	72.8	71.8	78.1
Streaming potential, mV	-220	-220	-222	-229	-232
Charge demand, µeq/l	6.4	6.9	7.4	7.9	8.1
Zeta potential, mV	-15.4	-15.1	-15.7	-16.2	-13.0
Conductivity, mS	0.477	0.477	0.469	0.460	0.449
Bulk, cc/g	1.50	1.50	1.47	1.48	1.46
Breaking length, m	1571	1931	1716	1741	1622
Burst index, kN/g	1.24	1.54	1.24	1.32	1.27
Tear index, mNm^2/g	6.17	6.24	6.21	6.07	5.98
Bending stiffness, mNm	0.098	0.111	0.099	0.090	0.086
Double fold, no.	4	5	4	5	5
Wax pick no.	4	6	3	2	6
ZD tensile strength, kPa	437	516	488	480	477
Air permeance, Gurley s	4.9	4.9	5.4	5.9	6.2
Bendtsen roughness, ml/min	194	229	214	205	200
Brightness, %ISO	87.5	86.8	87.4	88.3	91.3
Opacity, %ISO	88.8	88.2	88.5	87.7	88.8
Scattering coefficient, m^2/kg	51.7	49.2	50.8	51.4	51.8
CIE whiteness	113.0	113.3	113.5	113.9	114.7
Yellowness	-12.64	-11.09	-11.20	-10.84	-11.22
L*	94.6	93.8	94.0	94.2	94.4
a*	1.98	1.92	1.93	1.93	1.94
b*	-7.04	-6.24	-6.30	-6.14	-6.33

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 15 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BRS with GCC and CS, 5 kg/t at 15% ash level*

Table 117: Properties of BRC pulp with GCC and amphoteric strength additive at 5 kg/t

GCC addition, %	Reference*	25	30	36	42
Retained ash, %	15.5	15.7	19.0	21.9	24.1
FPAR, %	69.0	70.0	75.0	76.3	75.7
Streaming potential, mV	-220	-218	-221	-233	-236
Charge demand, µeq/l	6.4	6.1	6.7	7.4	8.5
Zeta potential, mV	-15.4	-16.4	-15.4	-14.0	-13.2
Conductivity, mS	0.477	0.470	0.461	0.455	0.449
Bulk, cc/g	1.50	1.49	1.47	1.46	1.45
Breaking length, m	1571	1693	1535	1548	1469
Burst index, kN/g	1.24	1.25	1.20	1.09	0.98
Tear index, mNm^2/g	6.17	6.02	5.15	5.06	4.58
Bending stiffness, mNm	0.098	0.097	0.094	0.090	0.085
Double fold, no.	4	5	3	3	3
Wax pick no.	4	4	3	2	0
ZD tensile strength, kPa	437	464	454	440	434
Air permeance, Gurley s	4.9	4.5	4.7	5.0	5.2
Bendtsen roughness, ml/min	194	240	233	228	225
Brightness, %ISO	87.5	87.3	87.8	88.4	89.2
Opacity, %ISO	88.8	88.4	88.7	88.8	88.9
Scattering coefficient, m^2/kg	51.7	49.0	51.7	53.2	53.8
CIE whiteness	113.0	113.3	113.3	113.7	114.1
Yellowness	-12.64	-10.86	-10.71	-10.63	-10.59
L*	94.6	94.0	94.2	94.4	94.6
a*	1.98	2.03	1.98	1.96	1.94
b*	-7.04	-6.18	-6.05	-6.06	-6.08

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 5 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BRS with GCC and CS, 5 kg/t at 15% ash level*

Table 118: Properties of BRC pulp with GCC and amphoteric strength additive at 10 kg/t

GCC addition, %	Reference*	25	30	36	42
Retained ash, %	15.5	16.2	19.9	22.5	24.5
FPAR, %	69.0	72.5	78.9	78.6	77.1
Streaming potential, mV	-220	-215	-220	-226	-231
Charge demand, µeq/l	6.4	6.0	6.5	7.2	8.0
Zeta potential, mV	-15.4	-16.1	-15.9	-14.7	-12.2
Conductivity, mS	0.477	0.470	0.466	0.455	0.451
Bulk, cc/g	1.50	1.49	1.48	1.46	1.45
Breaking length, m	1571	1922	1797	1743	1536
Burst index, kN/g	1.24	1.52	1.39	1.26	1.21
Tear index, mNm^2/g	6.17	6.38	6.10	5.94	5.26
Bending stiffness, mNm	0.098	0.101	0.099	0.093	0.088
Double fold, no.	4	6	4	4	4
Wax pick no.	4	4	3	2	4,3
ZD tensile strength, kPa	437	524	511	500	478
Air permeance, Gurley s	4.9	5.7	5.9	6.3	6.4
Bendtsen roughness, ml/min	194	222	196	192	188
Brightness, %ISO	87.5	86.9	87.1	87.4	87.6
Opacity, %ISO	88.8	88.4	89.4	89.6	89.7
Scattering coefficient, m^2/kg	51.7	49.1	52.4	53.2	56.4
CIE whiteness	113.0	113.0	113.3	113.4	113.5
Yellowness	-12.64	-10.69	-10.48	-10.42	-10.38
L*	94.6	93.6	94.1	94.2	94.4
a*	1.98	1.93	1.95	1.97	1.92
b*	-7.04	-5.85	-5.96	-5.95	-5.93

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 10 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BRS with GCC and CS, 5 kg/t at 15% ash level*

Table 119: Properties of BRC pulp with GCC and amphoteric strength additive at 15 kg/t

GCC addition, %	Reference*	25	30	36	42
Retained ash, %	15.5	16.5	20.4	22.2	23.4
FPAR, %	69.0	74.0	81.0	77.4	73.4
Streaming potential, mV	-220	-221	-224	-236	-241
Charge demand, µeq/l	6.4	5.9	6.2	7.1	7.3
Zeta potential, mV	-15.4	-16.7	-15.9	-15.1	-14.8
Conductivity, mS	0.477	0.472	0.468	0.450	0.443
Bulk, cc/g	1.50	1.50	1.48	1.47	1.45
Breaking length, m	1571	2002	1845	1821	1653
Burst index, kN/g	1.24	1.66	1.46	1.47	1.39
Tear index, mNm^2/g	6.17	6.87	6.61	6.28	5.92
Bending stiffness, mNm	0.098	0.112	0.100	0.094	0.091
Double fold, no.	4	6	5	6	5
Wax pick no.	4	6,7	6	4,6	4
ZD tensile strength, kPa	437	551	533	524	505
Air permeance, Gurley s	4.9	4.9	5.0	5.3	6.0
Bendtsen roughness, ml/min	194	232	225	215	191
Brightness, %ISO	87.5	87.4	88.0	88.6	89.3
Opacity, %ISO	88.8	88.3	88.6	88.8	89.3
Scattering coefficient, m^2/kg	51.7	49.2	50.2	50.7	52.3
CIE whiteness	113.0	112.6	113.0	114.0	113.5
Yellowness	-12.64	-10.82	-10.71	-10.56	-10.29
L*	94.6	93.6	93.9	93.6	94.0
a*	1.98	2.03	2.01	1.91	2.09
b*	-7.04	-6.14	-6.15	-5.57	-6.88

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 15 kg/t + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

** Reference: BRS with GCC and CS, 5 kg/t at 15% ash level*

Table 120: Properties of BRC pulp with PCC and cationic strength additive at 5 kg/t

PCC addition, %	Blank*	22	28	36	45
Retained ash, %	1.7	15.8	18.1	20.5	24.0
FPAR, %	-	78.2	75.0	71.0	71.9
Streaming potential, mV	-387	-220	-223	-236	-242
Charge demand, µeq/l	23.1	6.4	6.9	7.7	8.2
Zeta potential, mV	-20.7	-15.4	-15.2	-14.2	-13.0
Conductivity, mS	0.467	0.477	0.466	0.459	0.450
Bulk, cc/g	1.56	1.62	1.59	1.60	1.60
Breaking length, m	2186	1270	1259	1093	1269
Burst index, kN/g	1.65	1.14	1.04	1.02	0.93
Tear index, mNm^2/g	7.57	6.11	5.73	5.21	4.70
Bending stiffness, mNm	0.141	0.112	0.087	0.080	0.079
Double fold, no.	8	3	3	2	2
Wax pick no.	8	4	3	2	2
ZD tensile strength, kPa	438	429	422	416	388
Air permeance, Gurley s	6.2	4.5	4.7	4.9	5.4
Bendtsen roughness, ml/min	217	249	245	228	224
Brightness, %ISO	89.3	87.7	89.1	89.4	90.4
Opacity, %ISO	82.4	89.7	90.0	90.4	90.5
Scattering coefficient, m^2/kg	37.9	53.8	56.3	57.6	61.4
CIE whiteness	122.5	113.2	114.0	114.7	115.6
Yellowness	-13.98	-10.80	-10.76	-10.71	-10.65
L*	94.9	94.1	94.5	94.6	95.1
a*	2.19	1.90	1.87	1.96	1.93
b*	-6.12	-6.10	-6.09	-6.18	-6.17

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 5 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Blank: Unbeaten BRC pulp without addition of wet-end chemicals*

Table 121: Properties of BRC pulp with PCC and cationic strength additive at 10 kg/t

PCC addition, %	Reference*	22	28	36	45
Retained ash, %	15.8	15.0	18.5	21.1	25.1
FPAR, %	78.2	73.8	76.8	73.3	75.4
Streaming potential, mV	-220	-212	-221	-231	-236
Charge demand, µeq/l	6.4	6.2	6.3	7.0	7.9
Zeta potential, mV	-15.4	-15.1	-14.9	-14.7	-14.5
Conductivity, mS	0.477	0.471	0.469	0.461	0.455
Bulk, cc/g	1.62	1.60	1.59	1.58	1.57
Breaking length, m	1270	1430	1307	1155	1067
Burst index, kN/g	1.14	1.22	1.12	1.04	0.96
Tear index, mNm^2/g	6.11	6.23	6.04	5.68	5.40
Bending stiffness, mNm	0.112	0.114	0.089	0.084	0.081
Double fold, no.	3	4	3	3	2
Wax pick no.	4	3	3	2	2
ZD tensile strength, kPa	429	461	442	438	435
Air permeance, Gurley s	4.5	3.9	4.1	4.2	4.3
Bendtsen roughness, ml/min	249	280	252	245	-
Brightness, %ISO	87.7	87.4	89.0	89.7	90.5
Opacity, %ISO	89.7	88.8	89.5	90.1	90.4
Scattering coefficient, m^2/kg	53.8	50.9	55.2	56.4	56.8
CIE whiteness	113.2	114.7	115.0	115.3	115.5
Yellowness	-10.80	-10.96	-10.26	-10.03	-10.10
L*	94.1	94.0	94.4	94.8	94.6
a*	1.90	1.70	1.89	1.92	1.94
b*	-6.10	-5.42	-6.34	-6.25	-6.29

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 10 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: BRS with PCC and CS, 5 kg/t at 15% ash level*

Table 122: Properties of BRC pulp with PCC and cationic strength additive at 15 kg/t

PCC addition, %	Reference*	22	28	36	45
Retained ash, %	15.8	15.0	18.5	20.7	23.5
FPAR, %	78.2	73.8	76.8	71.8	70.2
Streaming potential, mV	-220	-211	-222	-241	-241
Charge demand, µeq/l	6.4	6.0	6.4	7.2	7.6
Zeta potential, mV	-15.4	-15.2	-14.9	-14.4	-14.5
Conductivity, mS	0.477	0.475	0.467	0.462	0.452
Bulk, cc/g	1.62	1.59	1.59	1.58	1.58
Breaking length, m	1270	1454	1381	1293	1101
Burst index, kN/g	1.14	1.37	1.22	1.08	1.04
Tear index, mNm^2/g	6.11	6.58	6.10	6.03	5.62
Bending stiffness, mNm	0.112	0.117	0.095	0.090	0.083
Double fold, no.	3	4	4	3	2
Wax pick no.	4	4	3	3	2
ZD tensile strength, kPa	429	467	460	456	444
Air permeance, Gurley s	4.5	4.2	4.3	4.5	4.6
Bendtsen roughness, ml/min	249	265	259	252	242
Brightness, %ISO	87.7	88.4	88.7	89.8	90.5
Opacity, %ISO	89.7	88.8	89.7	90.0	90.1
Scattering coefficient, m^2/kg	53.8	49.6	53.6	57.2	59.6
CIE whiteness	113.2	114.9	115.1	116.6	116.6
Yellowness	-10.80	-11.42	-10.81	-10.44	-10.29
L*	94.1	94.2	94.4	94.8	95.0
a*	1.90	1.93	1.85	1.95	1.93
b*	-6.10	-6.42	-6.11	-6.46	-6.39

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS, 15 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: BRS with PCC and CS, 5 kg/t at 15% ash level*

Table 123: Properties of BRC pulp with PCC and amphoteric strength additive at 5 kg/t

PCC addition, %	Reference*	22	28	36	45
Retained ash, %	15.8	15.1	18.0	21.6	24.4
FPAR, %	78.2	74.3	74.5	75.2	73.1
Streaming potential, mV	-220	-220	-223	-236	-242
Charge demand, µeq/l	6.4	6.4	6.9	7.7	8.2
Zeta potential, mV	-15.4	-15.4	-15.2	-14.2	-13.0
Conductivity, mS	0.477	0.477	0.466	0.459	0.450
Bulk, cc/g	1.62	1.59	1.59	1.58	1.57
Breaking length, m	1270	1650	1422	1305	1169
Burst index, kN/g	1.14	1.19	1.09	1.04	0.95
Tear index, mNm^2/g	6.11	6.01	5.40	4.92	4.64
Bending stiffness, mNm	0.112	0.102	0.089	0.083	0.081
Double fold, no.	3	3	3	2	2
Wax pick no.	4	4	3	3	2
ZD tensile strength, kPa	429	472	460	440	400
Air permeance, Gurley s	4.5	3.7	3.8	4.0	4.3
Bendtsen roughness, ml/min	249	276	261	258	244
Brightness, %ISO	87.7	88.6	89.0	89.9	90.6
Opacity, %ISO	89.7	89.4	89.6	90.3	90.7
Scattering coefficient, m^2/kg	53.8	52.3	54.8	59.6	62.3
CIE whiteness	113.2	114.8	115.1	116.2	116.5
Yellowness	-10.80	-11.51	-11.43	-11.23	-11.10
L*	94.1	94.2	94.4	94.8	95.2
a*	1.90	1.91	1.88	1.90	1.90
b*	-6.10	-6.46	-6.30	-6.44	-6.36

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 5 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: BRS with PCC and CS, 5 kg/t at 15% ash level*

Table 124: Properties of BRC pulp with PCC and amphoteric strength additive at 10 kg/t

PCC addition, %	Reference*	22	28	36	45
Retained ash, %	15.8	16.2	18.7	21.4	25.2
FPAR, %	78.2	80.4	77.7	74.4	75.7
Streaming potential, mV	-220	-219	-221	-232	-240
Charge demand, µeq/l	6.4	6.1	6.5	7.5	8.0
Zeta potential, mV	-15.4	-15.1	-15.0	-14.3	-13.8
Conductivity, mS	0.477	0.470	0.460	0.451	0.441
Bulk, cc/g	1.62	1.59	1.58	1.57	1.56
Breaking length, m	1270	1454	1381	1293	1101
Burst index, kN/g	1.14	1.48	1.37	1.13	0.97
Tear index, mNm^2/g	6.11	6.19	5.99	5.91	5.90
Bending stiffness, mNm	0.112	0.119	0.109	0.097	0.092
Double fold, no.	3	7	6	3	2
Wax pick no.	4	5	4	3	3
ZD tensile strength, kPa	429	494	488	480	449
Air permeance, Gurley s	4.5	3.2	3.3	3.7	4.2
Bendtsen roughness, ml/min	249	279	270	237	228
Brightness, %ISO	87.7	88.3	88.5	89.3	90.1
Opacity, %ISO	89.7	88.4	89.1	89.9	91.0
Scattering coefficient, m^2/kg	53.8	49.3	52.1	57.1	62.3
CIE whiteness	113.2	115.7	115.6	115.4	115.2
Yellowness	-10.80	-11.92	-11.71	-11.02	-10.82
L*	94.1	94.1	94.2	94.7	95.0
a*	1.90	1.96	1.95	1.84	1.80
b*	-6.10	-6.66	6.56	-6.29	-6.12

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 10 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: BRS with PCC and CS, 5 kg/t at 15% ash level*

Table 125: Properties of BRC pulp with PCC and amphoteric strength additive at 15 kg/t

PCC addition, %	Reference*	22	28	36	45
Retained ash, %	15.8	16.2	18.5	21.8	24.8
FPAR, %	78.2	80.4	76.8	75.9	74.4
Streaming potential, mV	-220	-219	-221	-232	-222
Charge demand, µeq/l	6.4	6.0	6.2	7.2	8.0
Zeta potential, mV	-15.4	-15.0	-14.2	-14.0	-13.1
Conductivity, mS	0.477	0.470	0.461	0.459	0.450
Bulk, cc/g	1.62	1.61	1.60	1.58	1.57
Breaking length, m	1270	1650	1422	1305	1169
Burst index, kN/g	1.14	1.55	1.39	1.32	1.17
Tear index, mNm^2/g	6.11	6.24	6.06	5.99	5.94
Bending stiffness, mNm	0.112	0.127	0.110	0.102	0.080
Double fold, no.	3	7	6	5	3
Wax pick no.	4	6	5	4	3
ZD tensile strength, kPa	429	512	493	484	454
Air permeance, Gurley s	4.5	4.8	4.0	3.6	3.3
Bendtsen roughness, ml/min	249	256	252	241	196
Brightness, %ISO	87.7	88.3	88.5	89.2	90.0
Opacity, %ISO	89.7	88.5	89.0	89.1	89.9
Scattering coefficient, m^2/kg	53.8	50.6	52.0	54.7	58.4
CIE whiteness	113.2	115.4	115.6	116.1	116.4
Yellowness	-10.80	-11.93	-11.53	-11.43	-11.28
L*	94.1	94.2	94.3	94.7	94.9
a*	1.90	1.91	1.90	1.95	1.92
b*	-6.10	-6.66	-6.46	-6.55	-6.38

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS, 15 kg/t + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

** Reference: BRS with PCC and CS, 5 kg/t at 15% ash level*

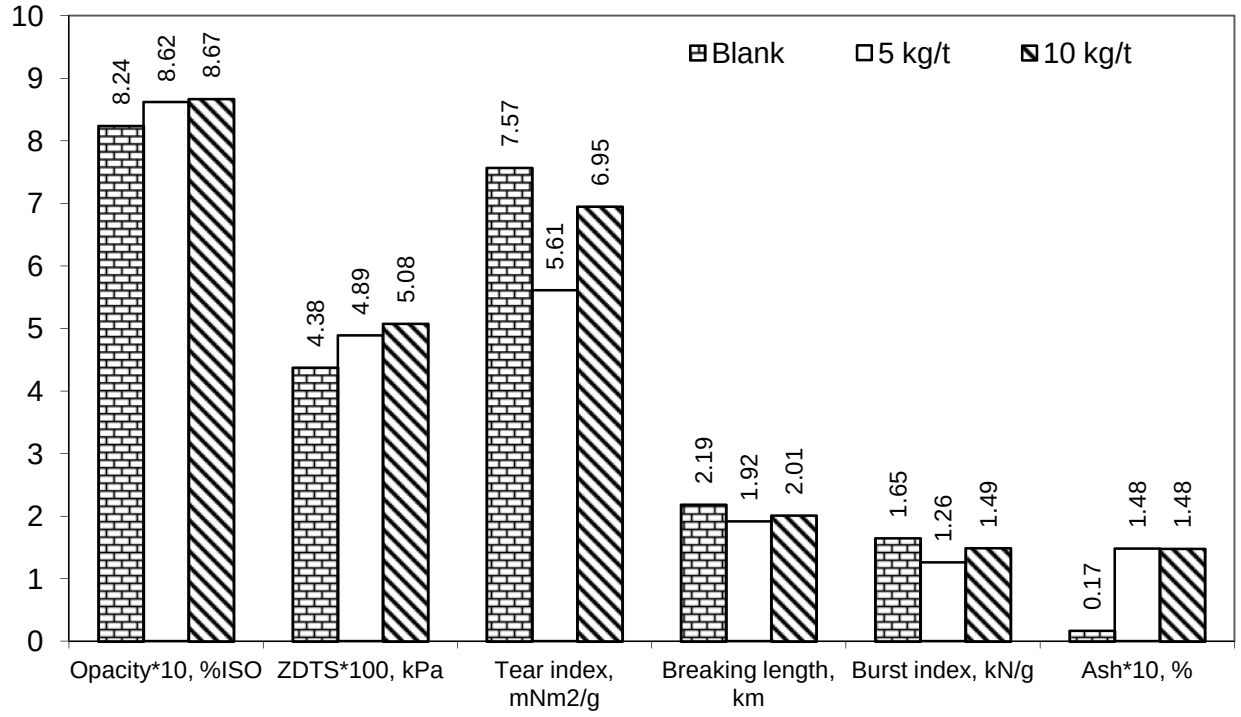

Figure 116: Effect of CS on properties of BRC pulp at 180 kg/t addition of talc

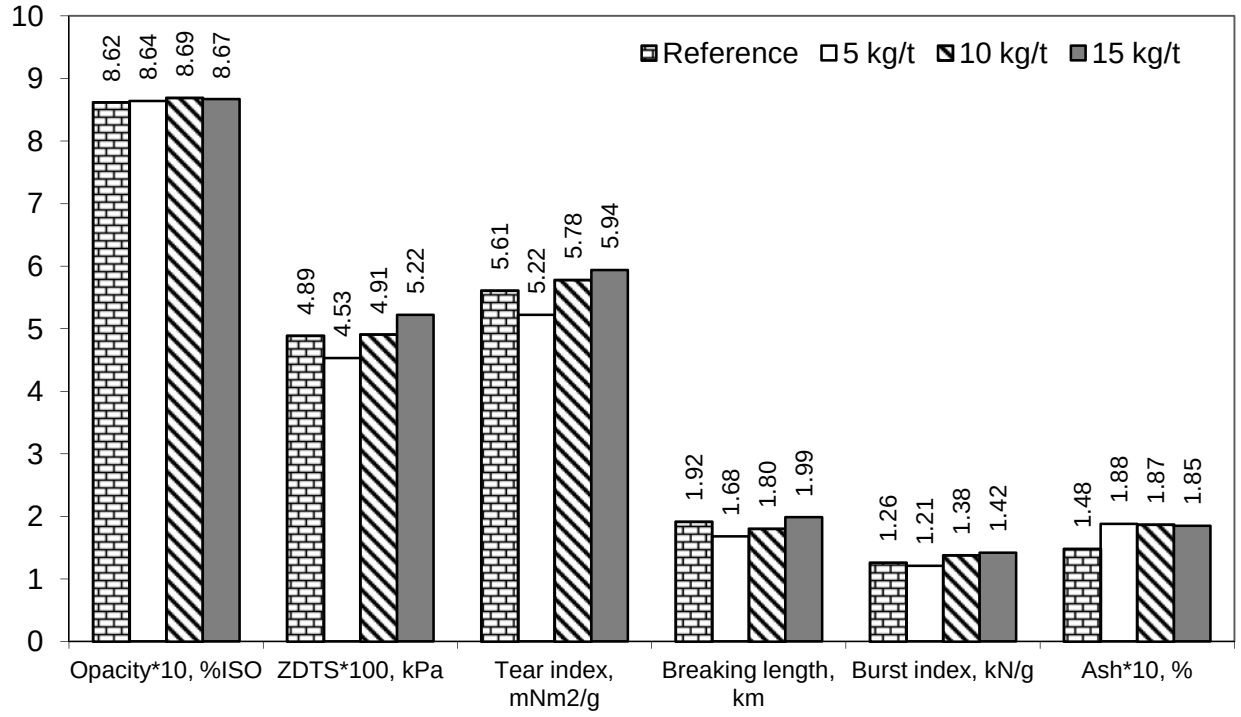

Figure 117: Effect of CS on properties of BRC pulp at 270 kg/t addition of talc

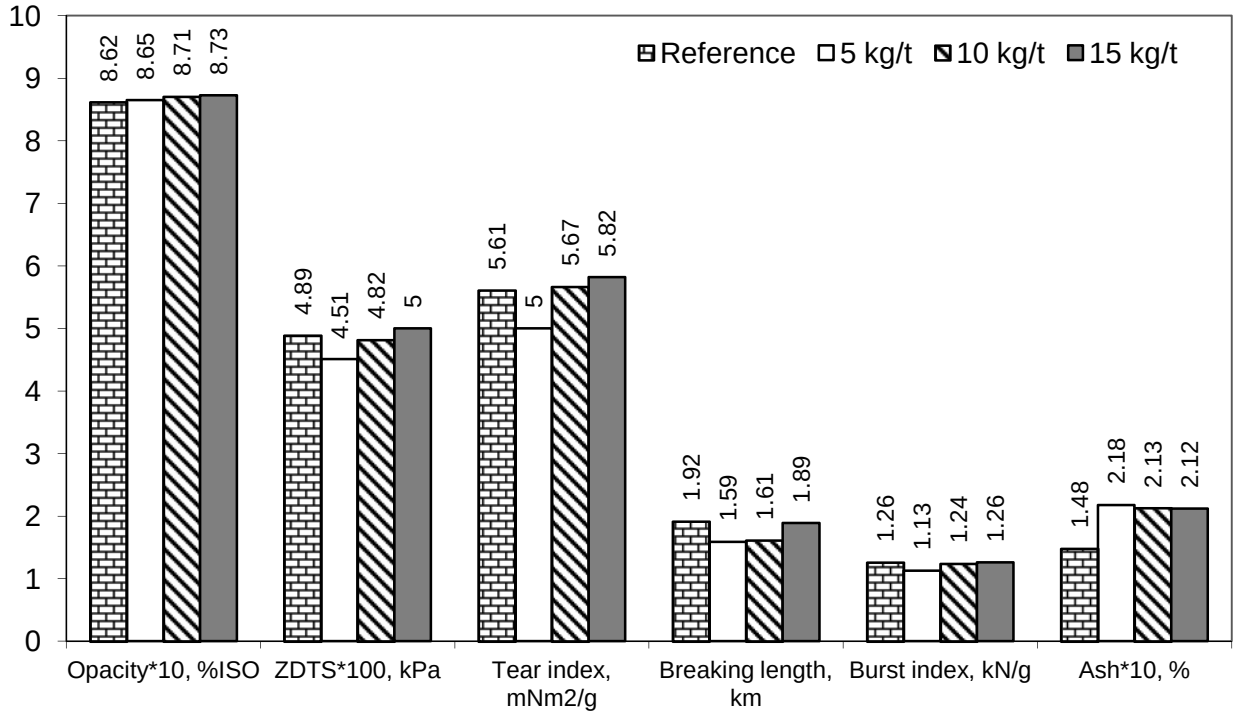

Figure 118: Effect of CS on properties of BRC pulp at 330 kg/t addition of talc

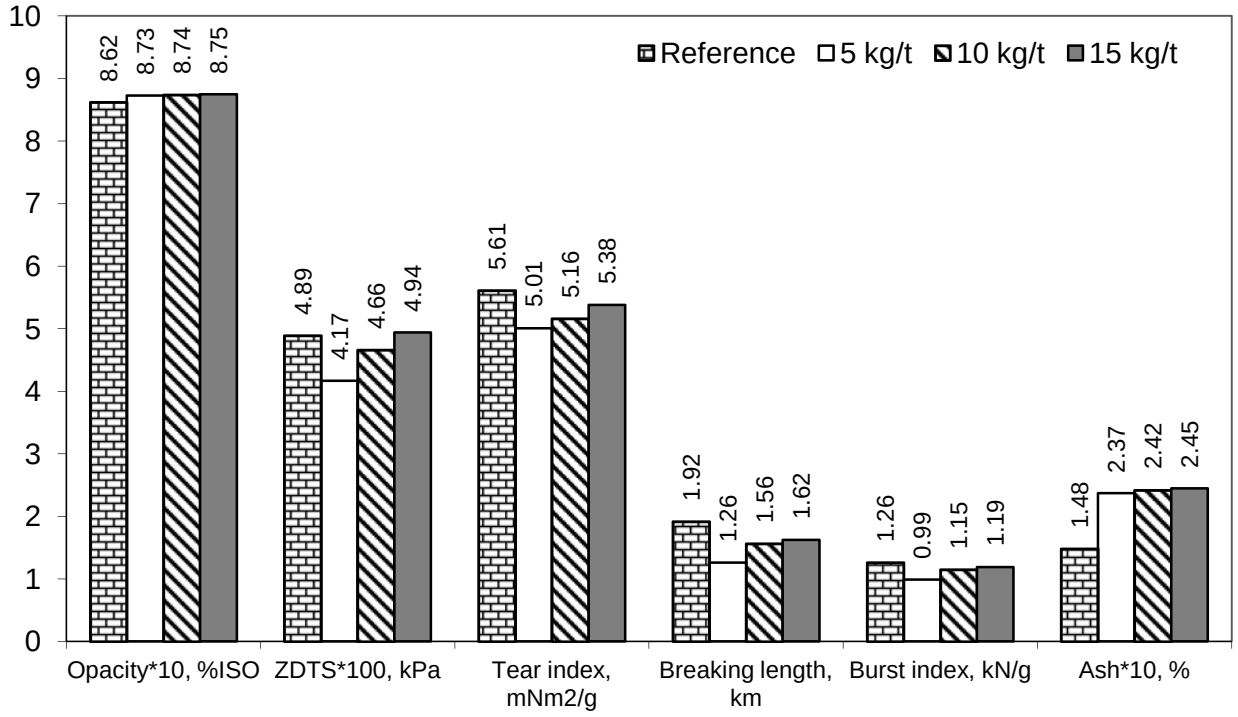

Figure 119: Effect of CS on properties of BRC pulp at 420 kg/t addition of talc

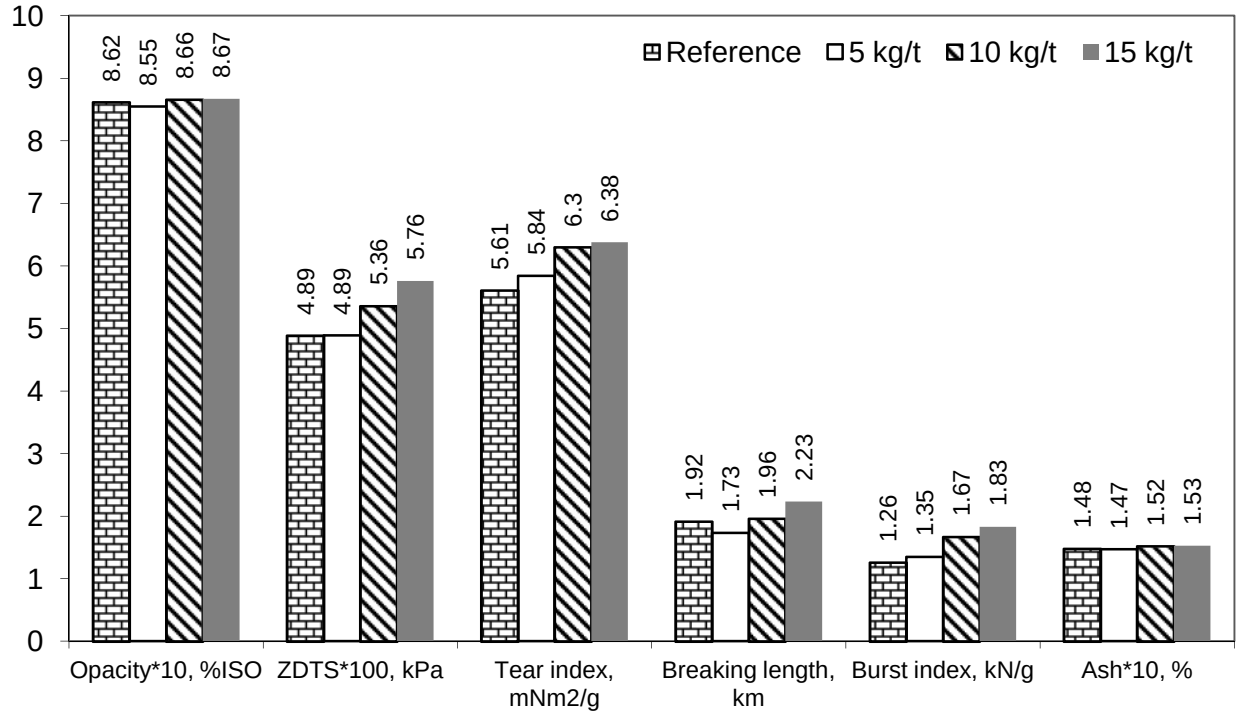

Figure 120: Effect of AS on properties of BRC pulp at 180 kg/t addition of talc

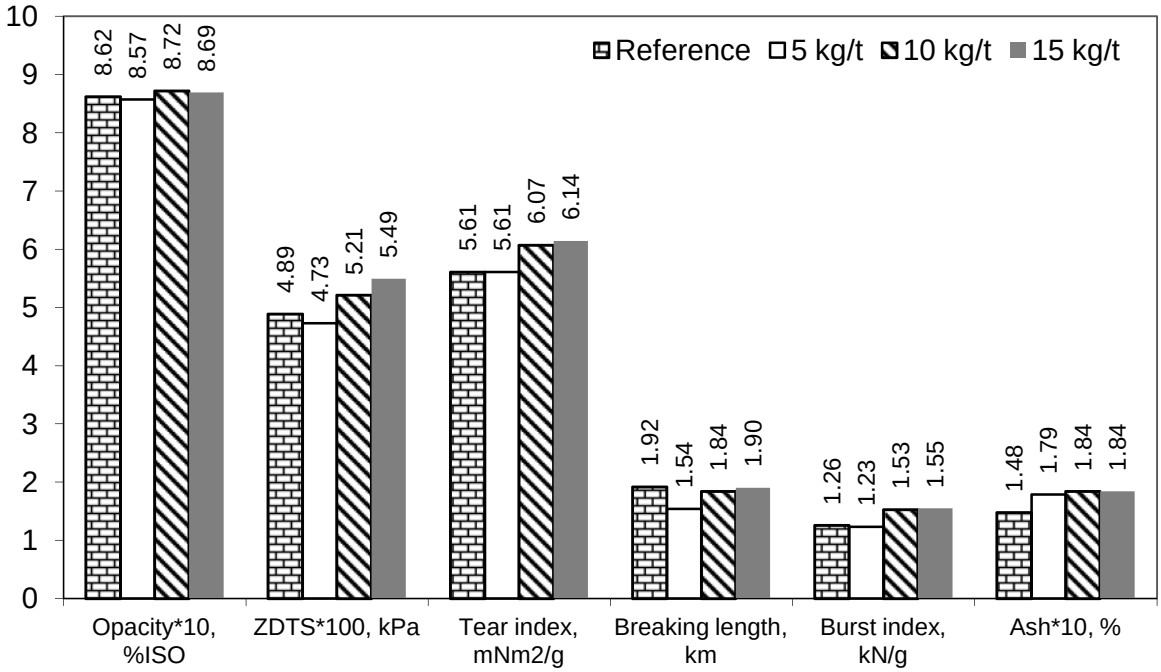

Figure 121: Effect of AS on properties of BRC pulp at 270 kg/t addition of talc

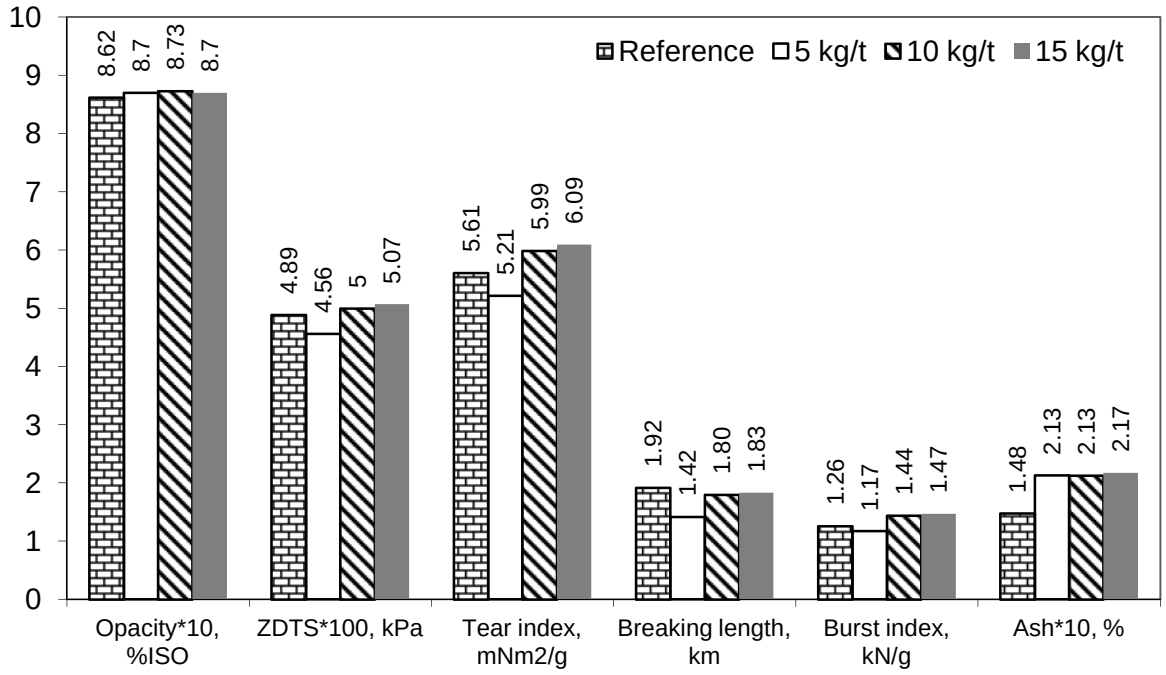

Figure 122: Effect of AS on properties of BRC pulp at 330 kg/t addition of talc

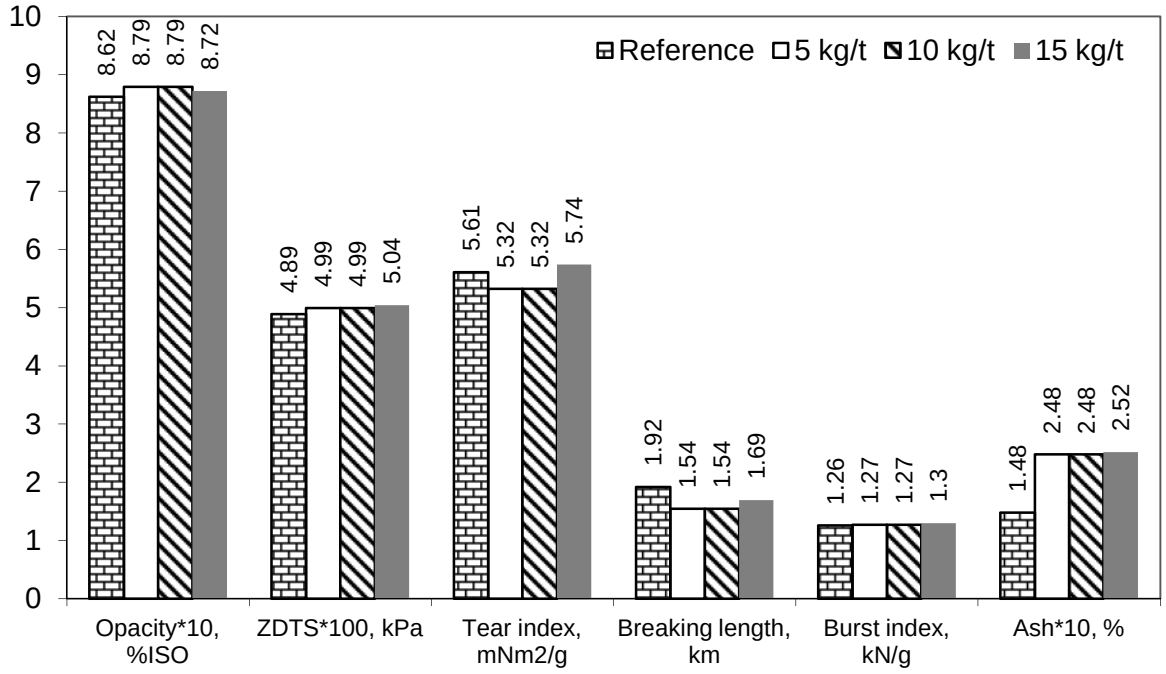

Figure 123: Effect of AS on properties of BRC pulp at 420 kg/t addition of talc

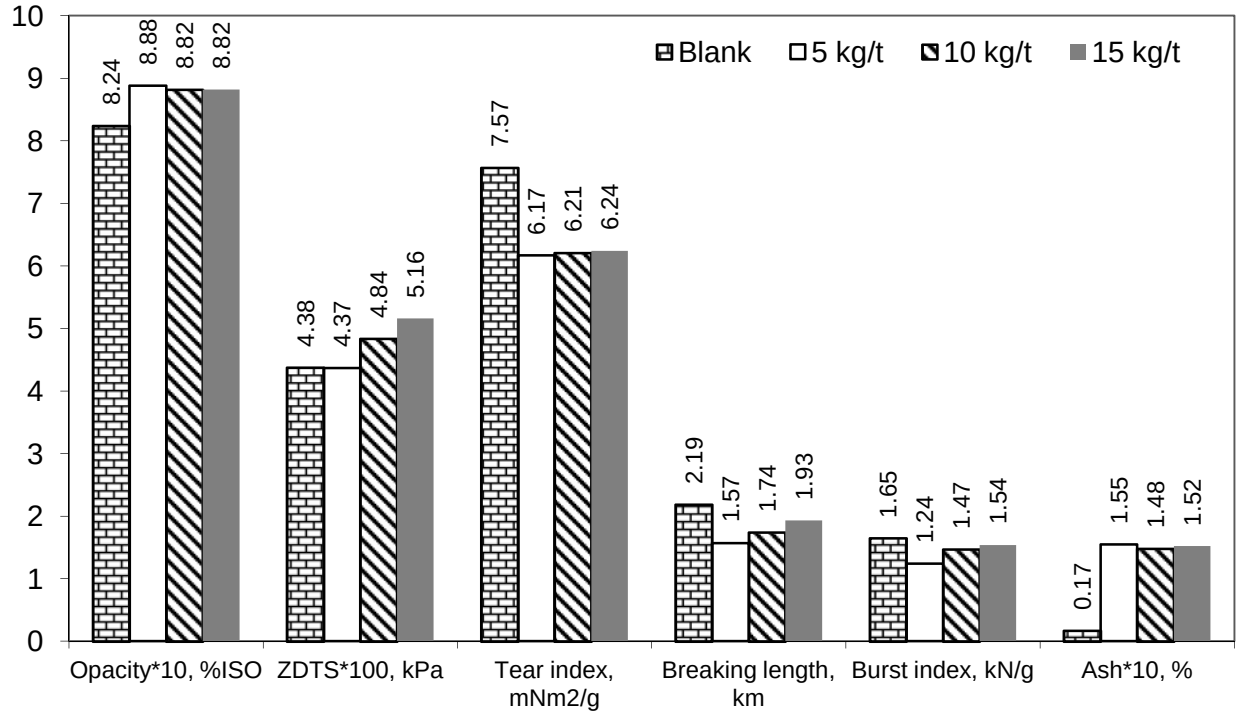

Figure 124: Effect of CS on properties of BRC pulp at 250 kg/t addition of GCC

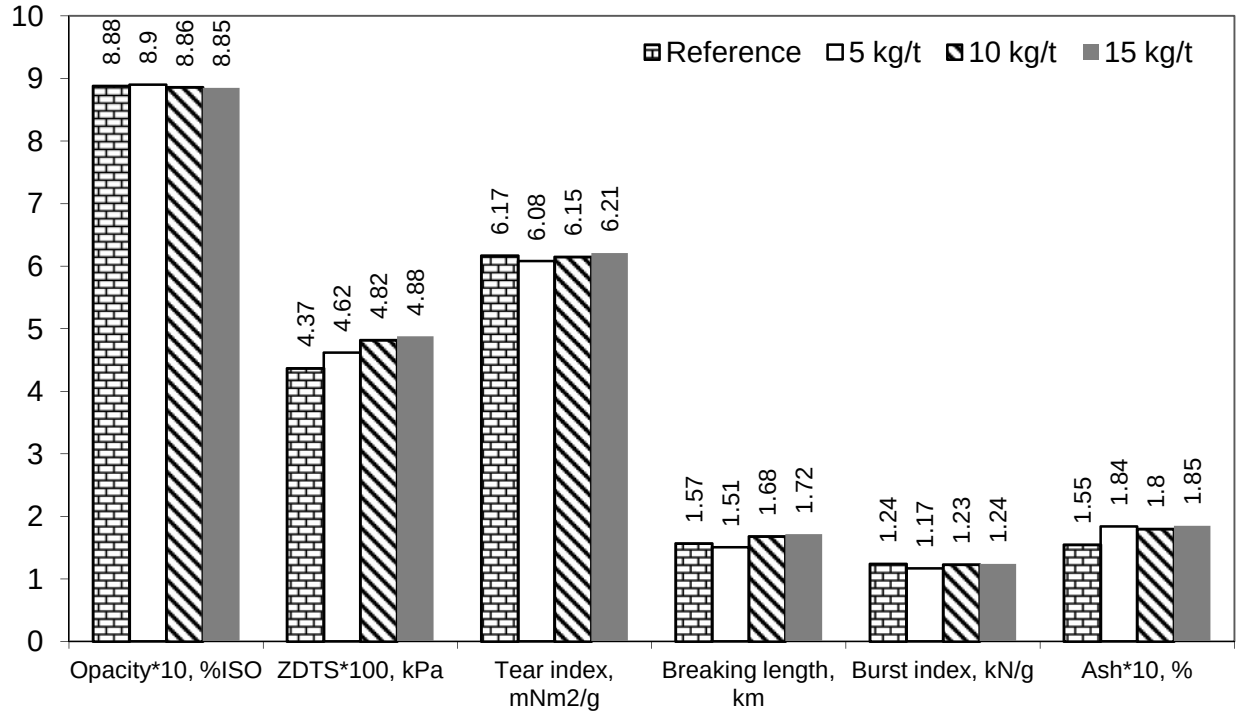

Figure 125: Effect of CS on properties of BRC pulp at 300 kg/t addition of GCC

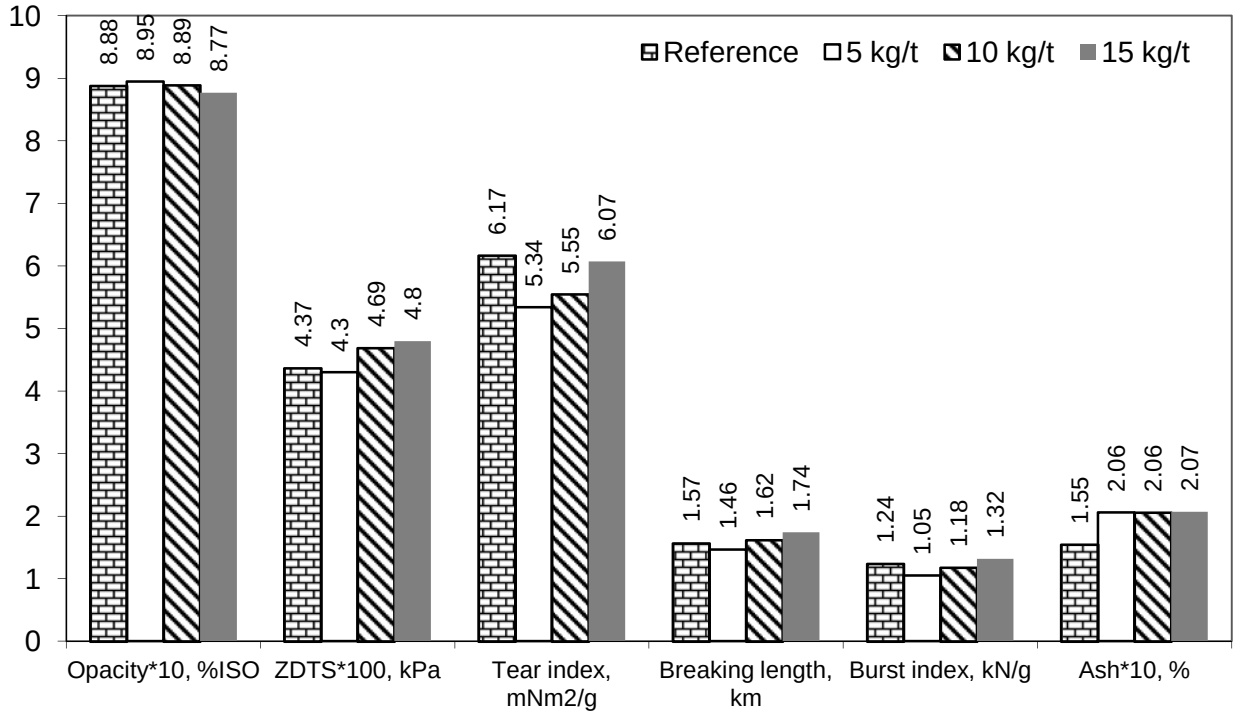

Figure 126: Effect of CS on properties of BRC pulp at 360 kg/t addition of GCC

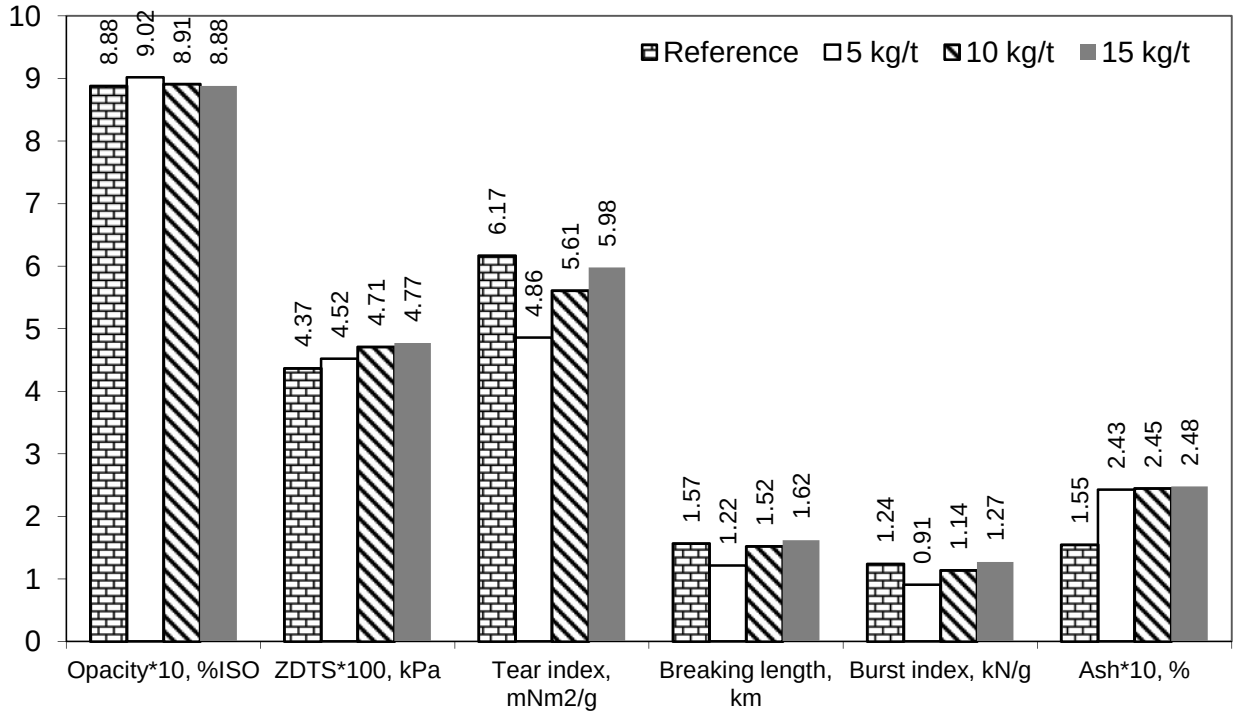

Figure 127: Effect of CS on properties of BRC pulp at 420 kg/t addition of GCC

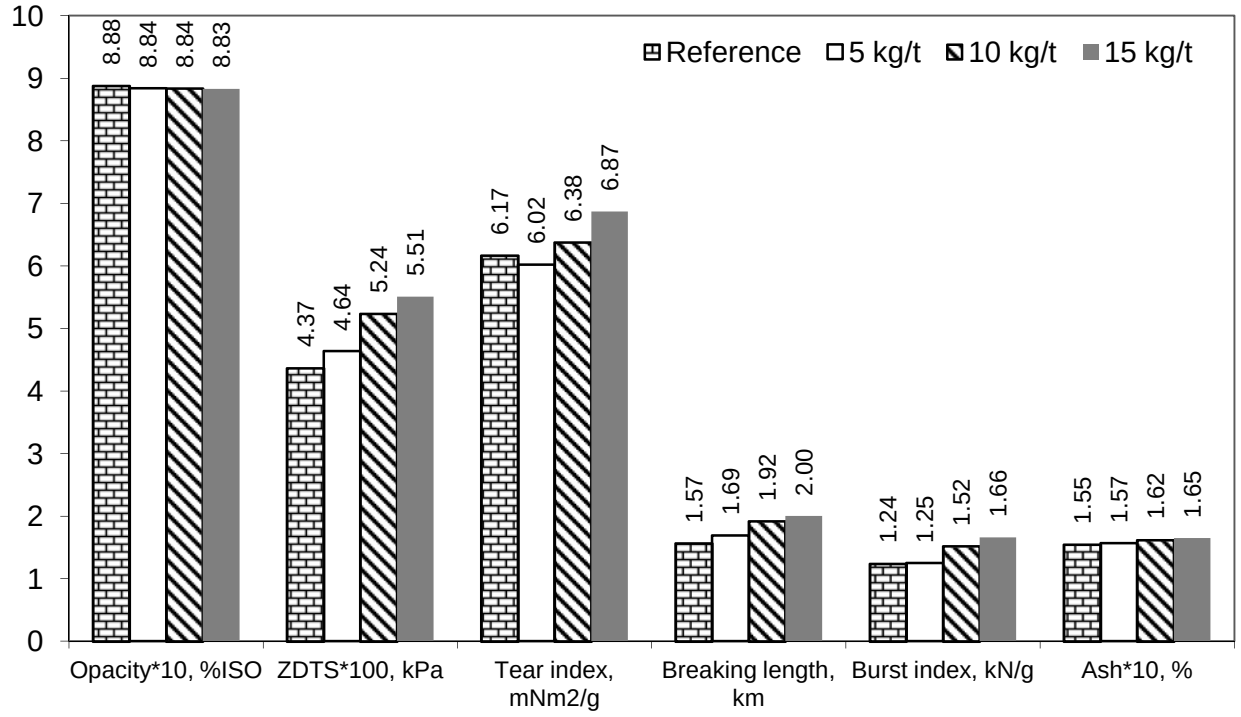

Figure 128: Effect of AS on properties of BRC pulp at 250 kg/t addition of GCC

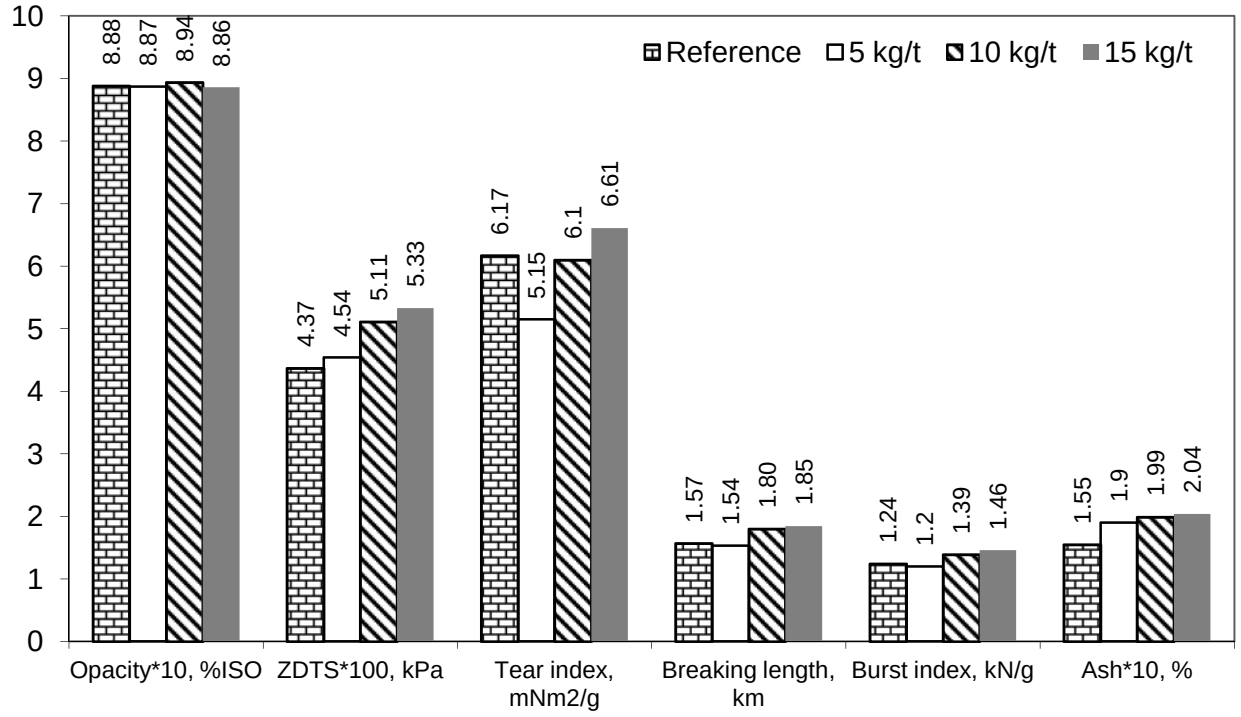

Figure 129: Effect of AS on properties of BRC pulp at 300 kg/t addition of GCC

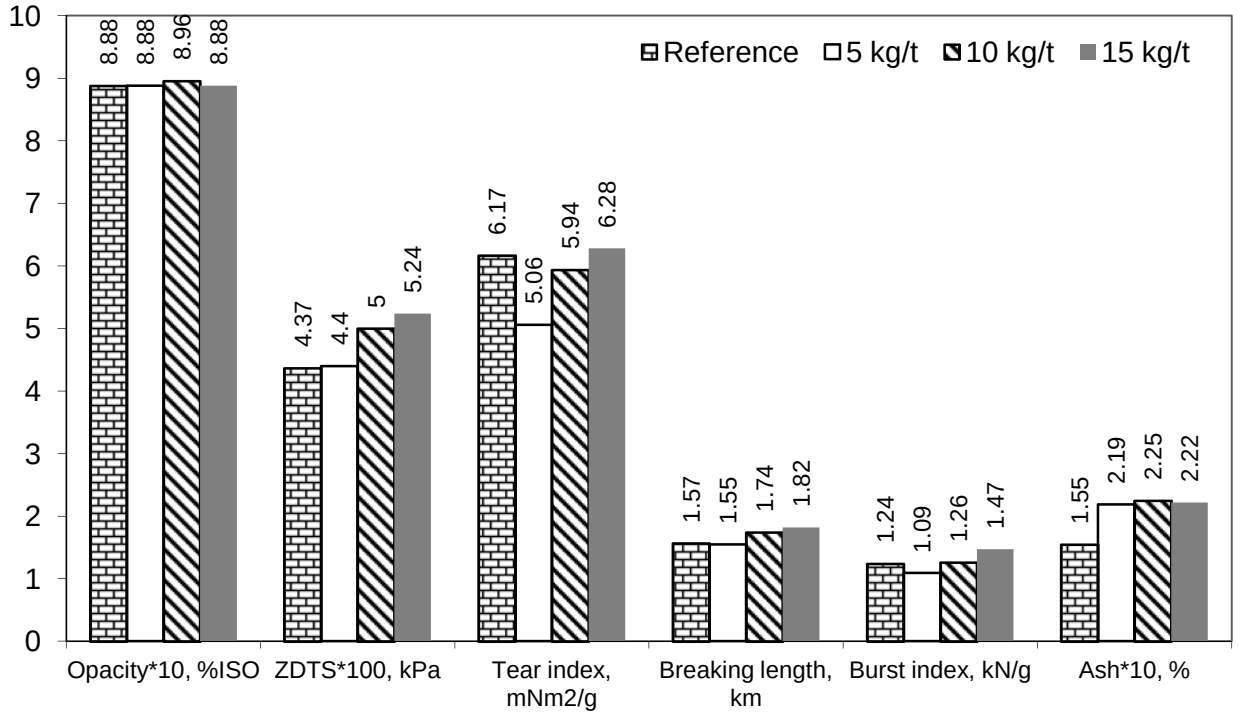

Figure 130: Effect of AS on properties of BRC pulp at 360 kg/t addition of GCC

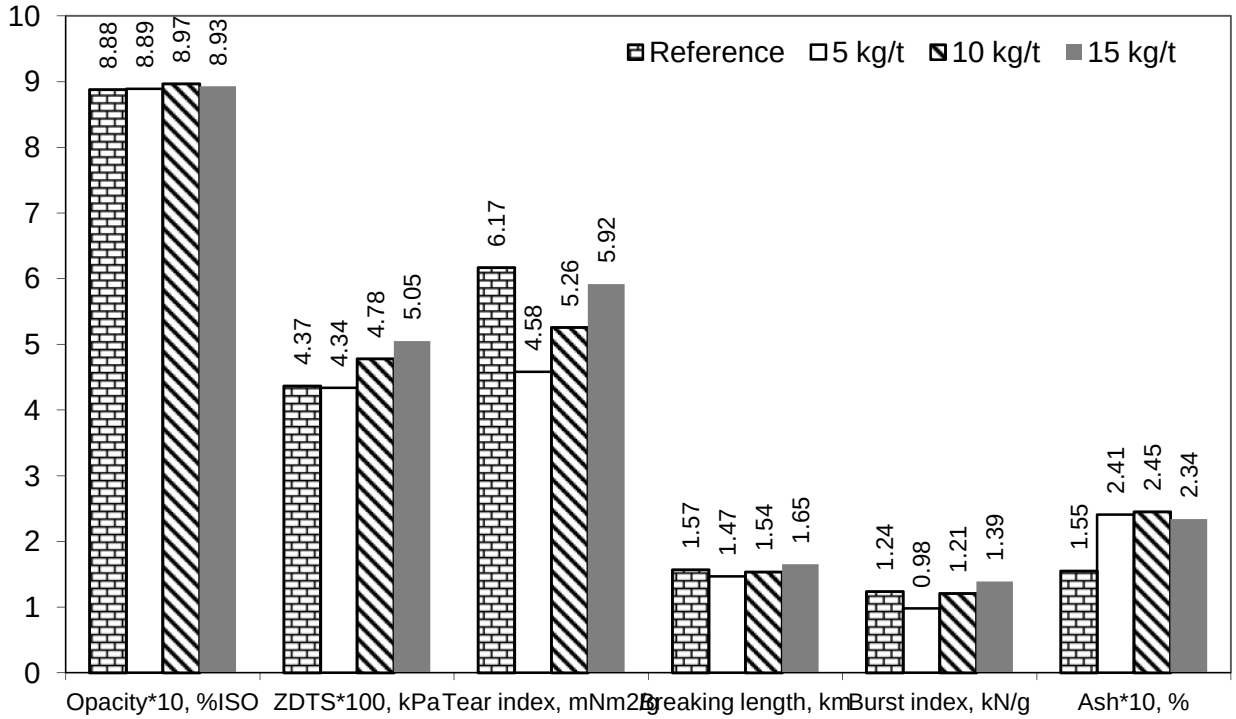

Figure 131: Effect of AS on properties of BRC pulp at 420 kg/t addition of GCC

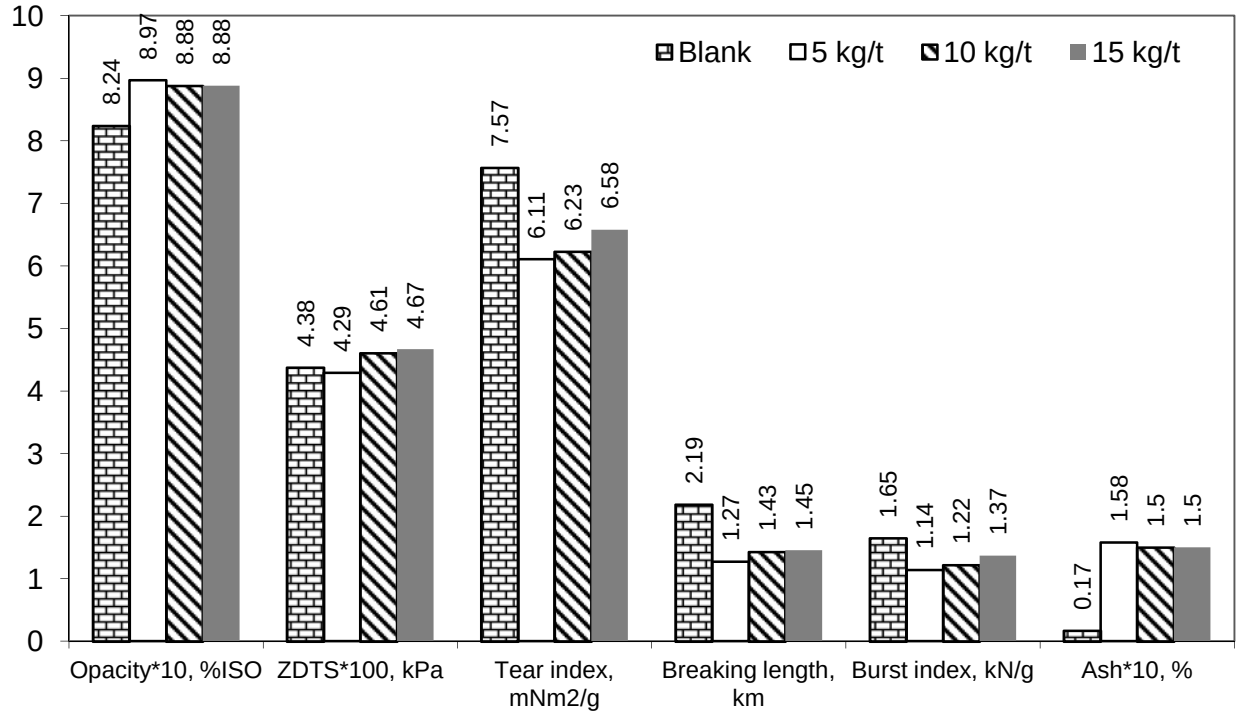

Figure 132: Effect of CS on properties of BRC pulp at 220 kg/t addition of PCC

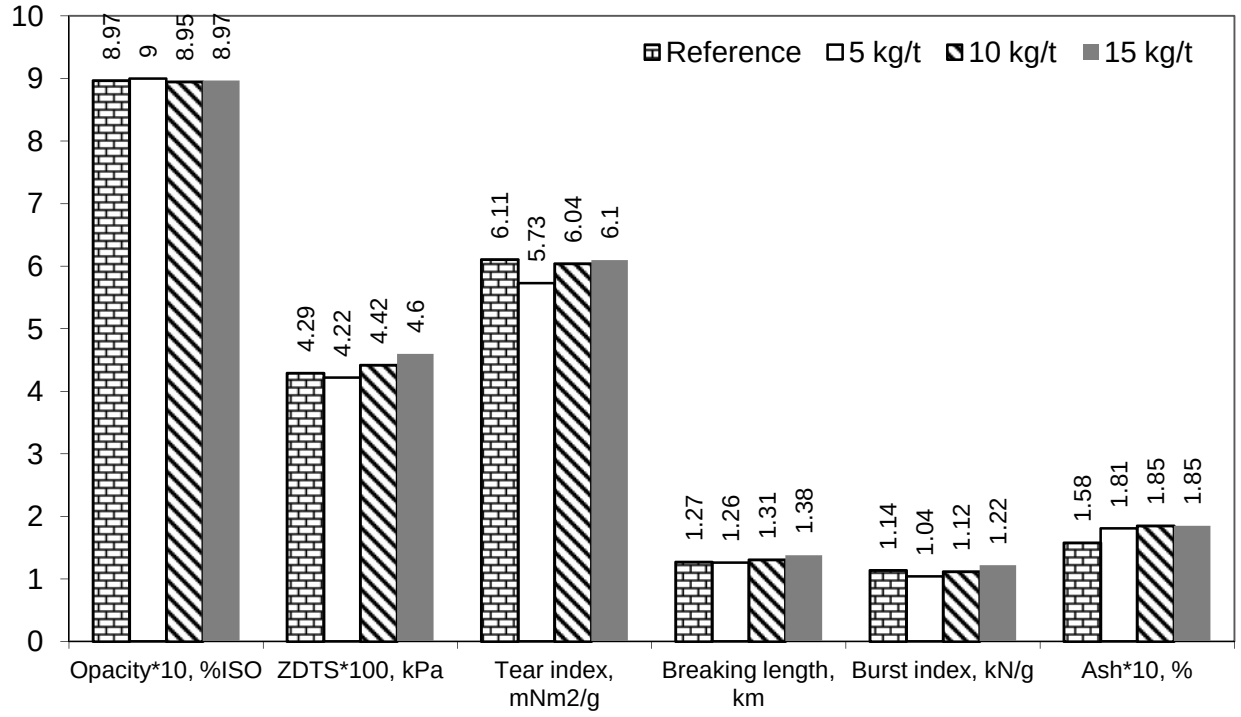

Figure 133: Effect of CS on properties of BRC pulp at 280 kg/t addition of PCC

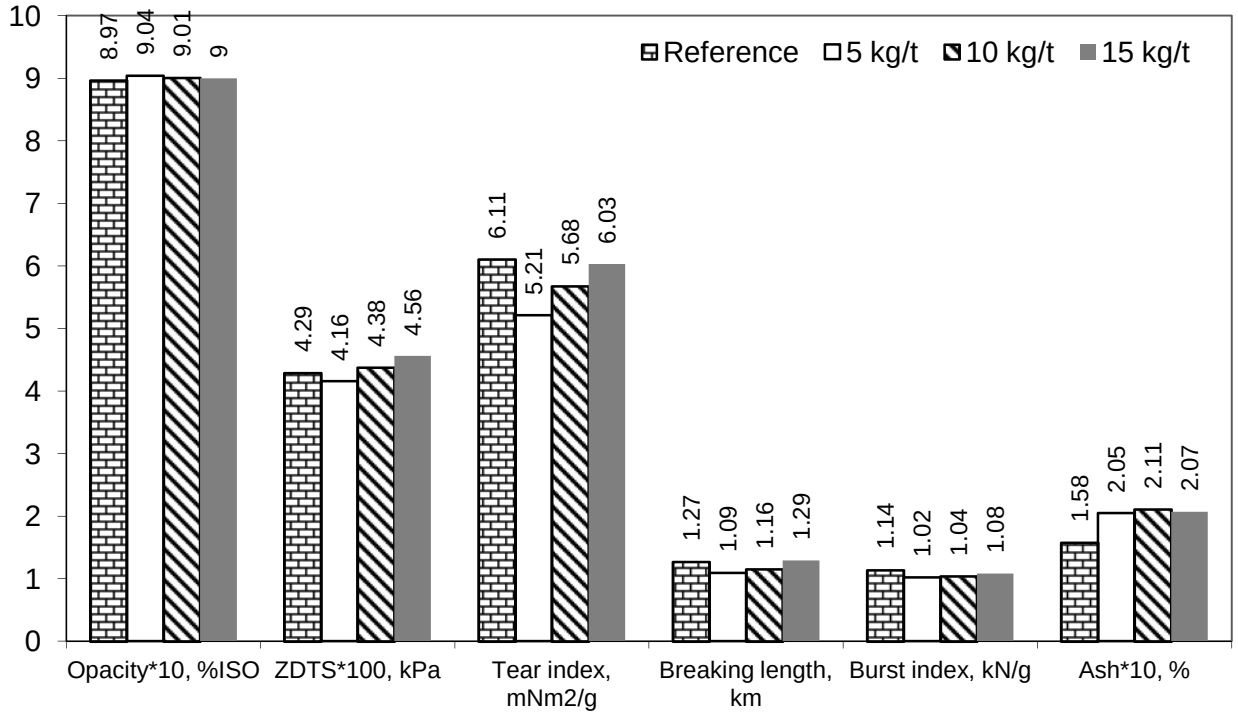

Figure 134: Effect of CS on properties of BRC pulp at 360 kg/t addition of PCC

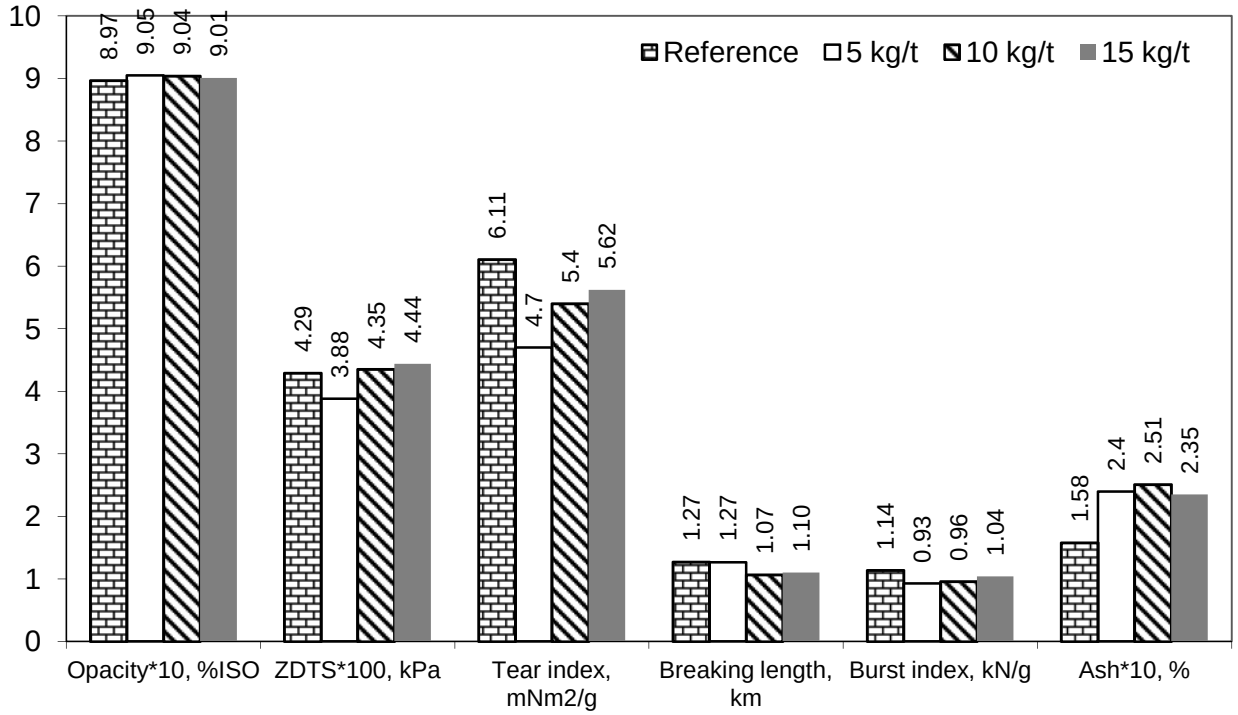

Figure 135: Effect of CS on properties of BRC pulp at 450 kg/t addition of PCC

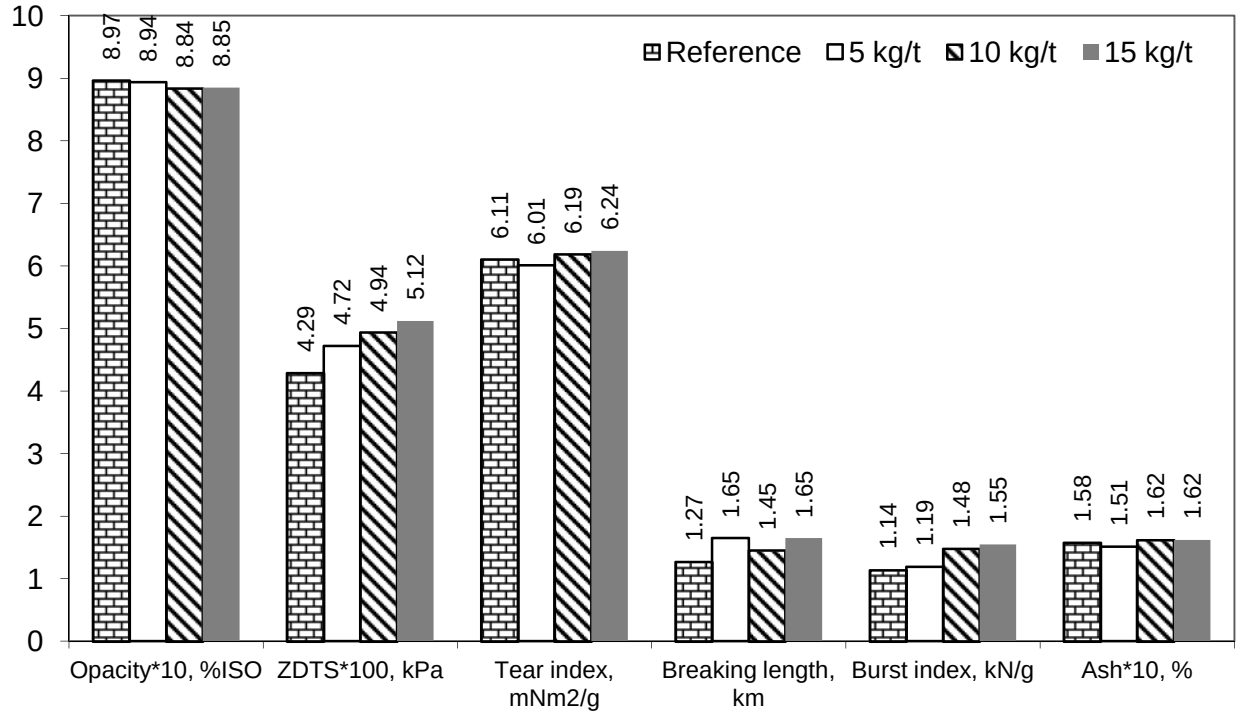

Figure 136: Effect of AS on properties of BRC pulp at 220 kg/t addition of PCC

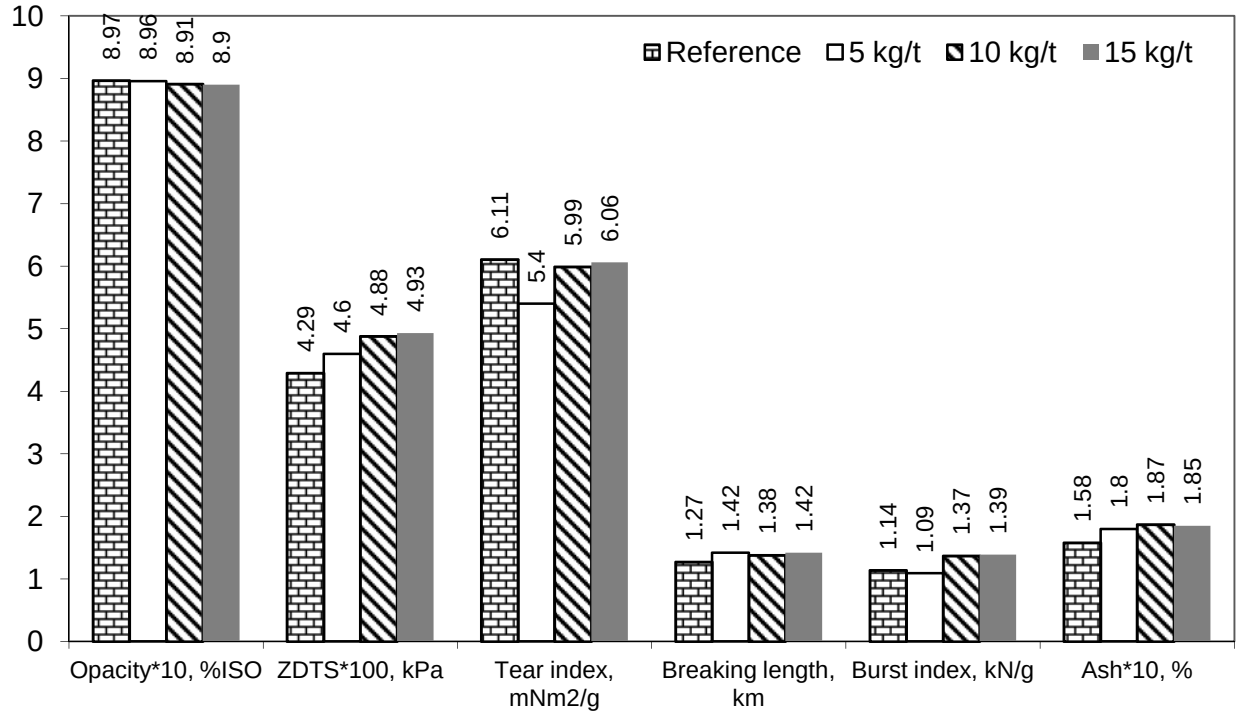

Figure 137: Effect of AS on properties of BRC pulp at 280 kg/t addition of PCC

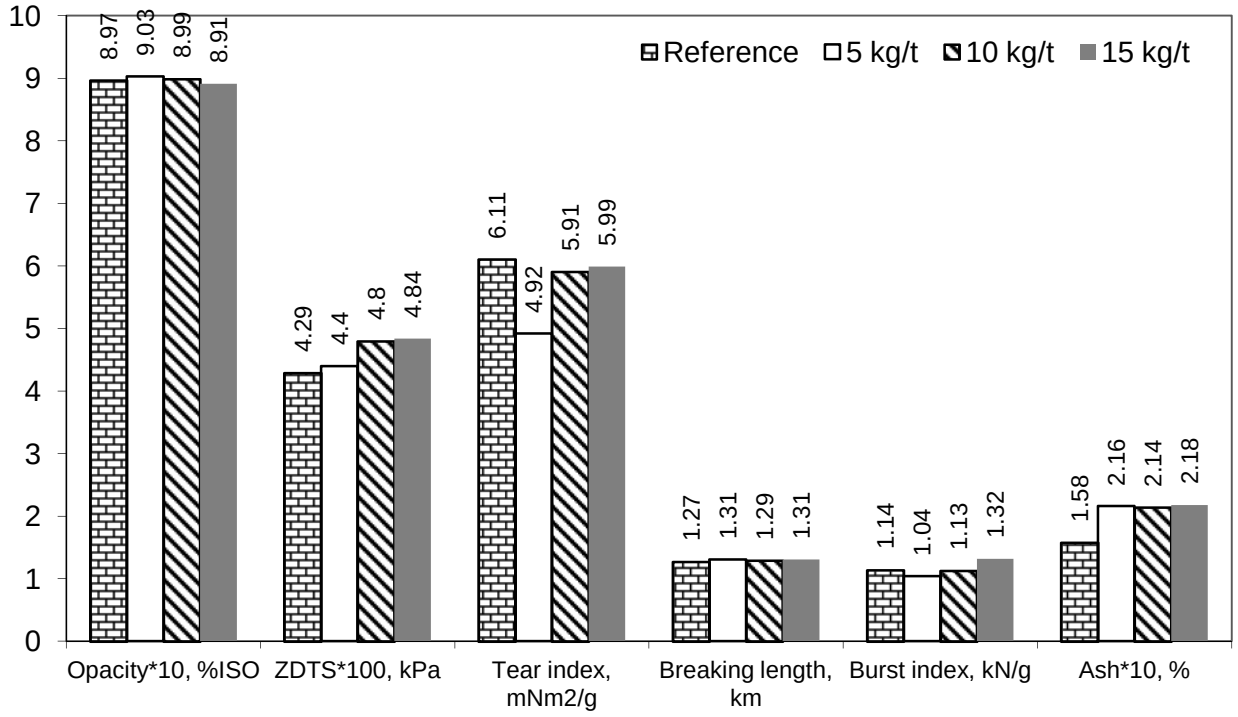

Figure 138: Effect of AS on properties of BRC pulp at 360 kg/t addition of PCC

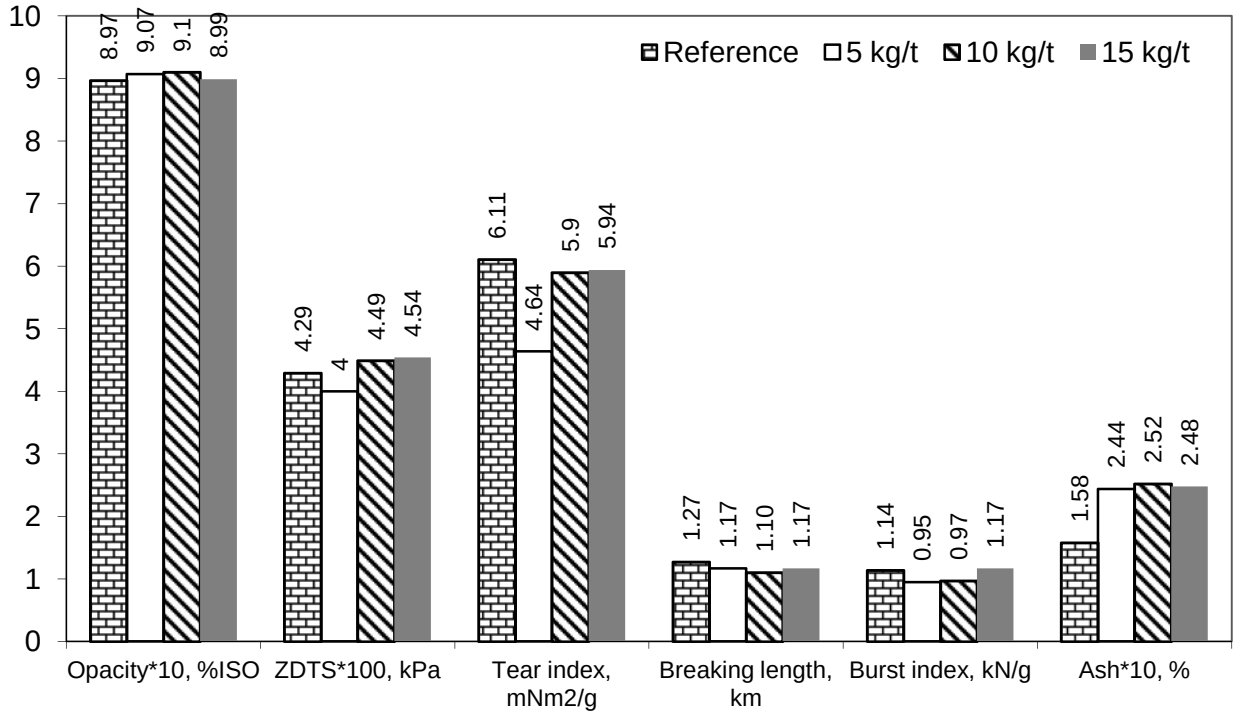

Figure 139: Effect of AS on properties of BRC pulp at 450 kg/t addition of PCC

CHAPTER – 6

Pretreatment of Fillers

RESULTS & DISCUSSION

The effect of different dry strength additives added in the wet-end of papermaking on various paper properties of different pulp furnishes has been discussed in the previous chapters. This chapter describes the effect of pre-treatment of filler (Talc, GCC and PCC) using cationic and amphoteric strength additives and cationic/ anionic polyacrylamides on hardwood and agro-residue based pulps.

6.1. Effect of pre-treatment of filler on paper made from hardwood pulp

6.1.1. Pre-treatment of talc filler

The split addition of the minimum dose of cationic and amphoteric strength additives i.e. 5 kg/t pulp was used for these experiments. The 10, 20 and 50% proportions of this dose i.e. 1.4, 2.8 and 7.0 kg/t (on dry filler), respectively were used for the pre-treatment of talc filler and the rest amount was added in the wet-end similar to previous experiments. In case of pre-treatment with CPAM, 5, 10 and 20% proportions of 200 g/t pulp dose i.e. 26, 52 and 104 g/t (on dry filler), respectively were used for the pre-treatment of talc filler and the rest amount was added in the wet-end as a retention aid.

As discussed earlier, the talc filler was anionic in nature. As shown in Table 126-128, the anionic charge of talc was reduced on pre-treatment with CS, AS and CPAM. The cationic demand of native talc was 1.7 µeq/g which reduced to 1.6, 1.4, 0.8, and 1.4, 0.8, 0.9 µeq/g on its pre-treatment using 1.4, 2.8 and 7.0 kg/t dose (on dry filler) of CS and AS, respectively (Table 126 & 127). In case of pre-treatment with CPAM, a sharp decline in the cationic demand of talc was observed. The cationic demand was reduced from 1.7 to 1.0, 0.5 and 0.3 µeq/g with the addition of CPAM dose of 26, 52 and 104 g/t on filler, respectively (Table 128).

As shown in Fig. 140, the size of filler flocs increased on increasing the dose of CS, AS or CPAM. The micro images taken on Image analyser reflected that the optimized dose of CS and AS was 2.8 and 1.4 kg/t; both gave comparable floc images. The optimized dose of CPAM was 52 g/t. Beyond the optimized dose levels, the uniformity of flocs got disturbed due to abrupt increase in the floc size.

The effect of talc pre-treated using CS on various paper properties is shown in Table 129. On pre-treating the talc at CS dose of 1.4 kg/t of filler, the FPAR was increase from 81.9 to 88.5% with the corresponding increase in ash content by 1.4 points. All strength properties were comparable to the corresponding ash level achieved by direct filler loading with a considerable gain in ZDTS, while bulk and optical properties remain unchanged. On further increasing the dose of CS to 2.8 kg/t on filler for pre-treatment of talc, FPAR was increased to 89.4% with the gain in ash by 1.6 points but no further gain in strength properties was observed. So the optimized dose of CS for the pre-treatment of talc was considered as 1.4 kg/t on filler basis.

As shown in Table 130, on pre-treatment of talc with AS, no appreciable change in filler retention and paper properties were observed. AS was added in filler at dose of 1.4 kg/t in filler which was 0.5 kg/t on pulp basis; rest 4.5 kg/t of pulp was added at the wet end. There was almost negligible effect of pre-treatment of talc with AS which was reflected by the values of FPAR and ash content. All the strength properties were comparable with pre-treated talc with AS dose of 1.4 kg/t on filler basis with no gain in ash content.

As shown in Table 131, the talc pre-treated with CPAM increased the FPAR from 81.9 to 86.1% with around 1 point gain in ash. These results were observed when 5 kg/t CS was added in the wet-end as a dry strength additive; without CS no significant improvement was observed. All strength properties were comparable with the corresponding ash level achieved by direct filler loading except ZDTS. On increasing the dose of CPAM to 52 g/t on filler, all strength properties were slightly improved with 1.2 points gain in ash. At this level, the ZDTS was also superior unlike previous case of 5% CPAM addition in filler. At CPAM dose of 104 g/t on filler, the gain in ash was around 1.9 points. All strength properties were comparable to that of the corresponding ash level achieved by direct filler loading.

It could be concluded that there was marginal increase in ash (1-2%) by pretreating the talc with either CS or CPAM without affecting the paper strength.

6.1.2. Pre-treatment of GCC filler

The pre-treatment of GCC filler was also carried out using CS, AS and CPAM. The CPAM provided abrupt increase in flocs size, so it was not used in the papermaking. The CS and AS were added at different doses for the pre-treatment of GCC filler. As shown in Table 132 & 133, the charge of native GCC filler was cationic which was slightly increased on its pre-treatment with CS and AS. The higher increase was observed with CS due to its only cationic groups. At CS dose of 2.6 kg/t on filler, the anionic demand of GCC slurry was 3.6 µeq/g which was increased to 4.7 µeq/g on increasing dose of CS to 6.6 kg/t on filler (Table 132). At AS dose of 1.3 kg/t on filler, the anionic demand of GCC slurry was 2.0 µeq/g which was increased to 3.5 on addition of 2.6 kg/t dose of AS in GCC filler (Table 133).

Micrographs of preflocculated GCC using CS, AS and CPAM are shown in Fig. 141 which reflected that the floc size was increased on the pre-treatment of GCC with either of the chemicals. The highest floc size was observed with CPAM.

The pre-treated GCC was added in the pulp stock and sheets were prepared. As shown in Table 134, the FPAR of GCC was increased from 55.5 to 63.3% when pre-treatment of GCC was done with 2.6 kg/t dose of CS on filler without addition of CS at wet-end and to 66.3% in the case when pre-treatment of GCC was done with CS dose of 2.6 kg/t of filler (1.3 kg/t on pulp) and rest of the strength additive i.e. 3.7 kg/t on pulp was added at wet-end. The increase in ash was around 2.5 and 3.5 points, respectively. All the strength properties were comparable to that of 21% ash level with direct filler loading except breaking length which got dropped by around

4%. On increasing the dose of CS for pre-treatment to 6.6 kg/t on filler, no further gain in ash and paper properties was observed.

In case of AS dose of 1.3 kg/t on filler for pre-treatment and 4.4 kg/t on pulp at wet-end, the FPAR was increased from 54.9 to 74.4% with the gain in ash by 6.3% as compared with the directly loaded filler at same level of addition. All strength properties were comparable to that of same ash level with direct filler loading. On increasing the AS dose to 2.6 kg/t of filler for pre-treatment of GCC, the FPAR was increased 75.3% (Table 135). In case of pre-treated GCC filler, the paper properties were slightly better than those in direct filler loading. The higher bonding capability between pre-treated filler and fibre was the reason for the increase in ash without much affecting the paper strength.

6.1.3. Pre-treatment of PCC filler

Similar to talc and GCC, PCC was also pre-treated using CS and AS, however due to its different retention aid chemical (APAM), it was also pre-treated with anionic polyacrylamide (APAM). The anionic demand of native PCC was 1.8 µeq/g which increased to 2.6 and 4.7 µeq/g on the pre-treatment of PCC with 2.6 and 6.6 kg/t dose of CS on dry filler, respectively (Table 136). In case of PCC pre-treated with 1.3 kg/t dose of AS, the anionic demand of PCC was increased from 1.8 to 3.9 µeq/g (Table 137). The charge results of pre-treated PCC with anionically charged APAM are shown in Table 138. The total dose of APAM used as a retention aid with PCC was 80 g/t on pulp basis. The 50% dose of total APAM i.e. 40 g/t on pulp (132 g/t on filler) was used for the pre-treatment of PCC which reduced the cationic charge of filler and converted it to anionic charge. The cationic harge demand of the pre-treated PCC filler was 0.3 1.3 µeq/g.

As shown in Fig. 142, the uniformity in floc size was observed with the CS dose of 2.6 kg/t and AS dose of 1.3 kg/t on filler. In case of APAM, the uniformity in flocs was up to APAM dose of 22 g/t on filler which was considered as the optimized dose for the pre-treatment of PCC on the basis of floc size. On increasing the dose further non-uniform and bigger flocs were formed.

The pre-treatment of PCC filler using CS at a dose of 0.9 kg/t pulp (2.6 kg/t filler) was very effective. It increased the ash in paper from 17.1 to 20.5% (3.4 points) without adversely affecting the paper strength. If the total doe of CS (5 kg/t pulp) is divided in two parts; 0.9 kg/t for pre-treatment of PCC and 4.1 kg/t at the wet-end, it increased the ash from 17.5 to 20.6% (3.1 points). In this case little drop in paper strength was observed as compared that with native talc at 17.5% ash (Table 139).

The effect of pre-treated PCC using AS is shown in Table 140. AS was very effective as a pre-treatment for PCC filler. The pre-treated PCC filler using AS at a dose of 0.5 kg/t pulp (1.3 kg/t filler) increased the ash in paper from 17.1 to 21.5% (4.4 points). Even the paper strength including ZDTS and tear were also higher with the pre-treated PCC filler and at higher ash level. If the total doe of CS (5 kg/t pulp) is divided in two parts; 0.5 kg/t for pre-treatment of PCC and

4.5 kg/t at the wet-end, it increased the ash from 18.9 to 22.1% (3.2 points). In this case too there was no adverse effect of increased ash in paper due to pre-treatment of PCC using AS (Table 140).

On pre-treatment of PCC with 22 g/t of APAM on filler the ash was increased from 17.5 to 21.4% (3.9 points). In this case the paper strength was decreased on the loading of pre-treated PCC filler in paper. However if compared at the same ash level (21-22%), the paper strength of both native and pre-treated PCC filler was comparable which indicated the effectiveness of APAM in saving the filler to get the similar paper strength (Table 141).

6.2. Effect of pre-treatment of filler on paper made from wheat straw pulp

The effect of pre-treatment of different fillers using CS, AS, CPAM/APAM on charge and floc size has already been discussed earlier in this chapter. Their impact of paper properties of wheat straw pulp is discussed below. In this case, the pre-treated talc was not used as it was not having much potential for either increasing ash or paper strength.

6.2.1. Pre-treatment of GCC filler

Similar to the hardwood pulp, the pre-treated GCC filler was added in the wheat straw pulp and its impact on paper properties is shown in Table 142. If only 0.8 kg/t pulp (2.6 kg/t filler) dose of CS is used for the pre-treatment of GCC filler and no CS is added in the wet-end, the increase in ash was from 18.5 to 19.3% (0.8 point). It also provided comparable paper properties to the case of native talc without CS addition. If the total dose of CS (5 kg/t pulp) is divided in two parts; 0.4 kg/t for pre-treatment of GCC and 4.6 kg/t at the wet-end, it increased the ash from 18.3 to 19.3% (1 point). It gave comparable paper properties with little decrease in tear and ZDTS. When dose for the pre-treatment was increased to 0.8 kg/t pulp (2.6 kg/t filler) and rest of the CS (4.2 kg/t pulp) was added at the wet-end, the ash was increased from 18.3 to 20.5% (2.2 points). When compared at the same ash level (21-22%), the paper strength of both native and pre-treated GCC filler was comparable which indicated the effectiveness of filler pre-treatment in saving the filler to get the similar ash and paper strength.

The effect of pre-treated GCC filler using AS on various paper properties is shown in Table 143. When 0.4 kg/t pulp (1.3 kg/t filler) dose of AS was used for the pre-treatment of GCC filler and no AS was added in the wet-end, there was no appreciable increase in the ash content, however, the paper strength was slightly increased. When the total dose of AS (5 kg/t pulp) was divided in two parts; 0.4 kg/t for pre-treatment of GCC and 4.6 kg/t at the wet-end, the ash was increased from 19.4 to 20.7% (1.3 points). It also provided paper with comparatively higher strength. When the doe of AS for pre-treatment was increased 0.8 kg/t pulp (2.6 kg/t filler) and rest of the AS (4.2 kg/t pulp) was added at the wet-end, the ash was increased from 19.4 to 23.8% (4.4 points). This also provided the comparable strength to that of native GCC filler at 19.4% ash level.

6.2.2. Pre-treatment of PCC filler

The pre-treatment of PCC filler was also carried out using CS and AS. The effect of pre-treated PCC using CS on various paper properties is shown in Table 144. In this case, when only 0.9 kg/t pulp (2.6 kg/t filler) dose of CS was used for the pre-treatment of PCC filler and no CS was added in the wet-end, the ash was increased from 18.1 to 19.6% (1.5 points). It also provided either comparable or higher paper strength than that with native talc without CS addition. When in addition to the pre-treatment of PCC, the rest amount of CS i.e. 4.2 kg/t (out of total 5 kg/t pulp) was also added at the wet-end, the ash was increased from 18.4 to 20.4% (2 points). The paper strength at this ash level was even higher than that with native PCC at lower (18.4%) ash level.

The effect of pre-treated PCC filler using AS on various paper properties is shown in Table 145. When 0.5 kg/t pulp (1.3 kg/t filler) dose of AS was used for the pre-treatment of PCC filler and no AS was added in the wet-end, the ash content in paper was increased from 18.1 to 22.8% (4.7 points). It also provided paper with comparatively higher strength. When in addition to the pre-treatment of PCC, the rest amount of AS i.e. 4.5 kg/t (out of total 5 kg/t pulp) was also added at the wet-end, the ash was increased from 19.0 to 23.1% (4.1 points). In this case few paper properties were comparable and few were slightly lower than that of paper filled with native PCC at 19.0% ash level. When the properties of paper prepared from pre-treated and native PCC are compared at similar ash level of 23-24%, it was observed that the pre-treated PCC gave comparatively higher strength to paper than native PCC.

Table 126: Charge analysis of the pretreated talc (20% w/v) using different doses of cationic strength additive

CS dose		Charge, mV	Charge demand, µeq/g
% of 5 kg/t	kg/t filler		
0	0	-710	1.7
10	1.4	-688	1.6
20	2.8	-574	1.4
50	7.0	-462	0.8

Table 127: Charge analysis of the pretreated talc (20% w/v) using different doses of amphoteric strength additive

AS dose		Charge, mV	Charge demand, µeq/g
% of 5 kg/t	kg/t filler		
0	0	-710	1.7
10	1.4	-622	1.4
20	2.8	-511	0.8
50	7.0	-538	0.9

Table 128: Charge analysis of the pretreated talc (20% w/v) using different doses of CPAM

CPAM dose		Charge, mV	Charge demand, µeq/g
% of 200 g/t	g/t filler		
0	0	-710	1.7
5	26	-511	1.0
10	52	-412	0.5
20	104	-288	0.3

Table 129: Pretreatment of talc with cationic strength additive and its addition in MHB pulp

Talc addition, %	27	27	27	27	27	27
CS in filler, kg/t of filler	0	0	1.4	1.4	2.8	7.0
CS in wet-end, kg/t of pulp	0	5	0	4.6	4.2	3.1
Total CS, kg/t of pulp	0	5	0.4	5	5	5
Retained ash, %	18.3	17.4	19.0	18.8	19.0	18.8
FPAR, %	86.1	81.9	89.4	88.5	89.4	88.5
CSF, ml	570	540	551	600	547	550
Streaming potential, mV	-206	-192	-223	-220	-226	236
Charge demand, µeq/l	4.7	7.7	7.0	7.4	7.2	8.1
Zeta potential, mV	-19.7	-19.3	-19.8	-18.7	-18.8	-17.9
Conductivity, mS	0.456	0.398	0.458	0.451	0.449	0.452
Bulk, cc/g	1.25	1.25	1.26	1.25	1.27	1.28
Breaking length, m	3727	4196	3971	4151	4144	4077
Burst index, kN/g	2.54	2.71	2.42	2.80	2.68	2.66
Tear index, mNm^2/g	6.30	6.56	6.27	6.41	6.23	6.20
Bending stiffness, mNm	0.145	0.160	0.157	0.167	0.142	0.163
Double fold, no.	20	26	16	26	24	27
ZD tensile strength, kPa	701	720	648	764	749	759
Air permeance, Gurley s	15.1	15.7	12.0	12.9	13.3	13.8
Bendtsen roughness, ml/min	99	93	109	102	102	105
Brightness, %ISO	81.6	81.1	81.6	81.3	81.1	81.3
CIE whiteness	67.6	67.3	68.3	67.8	67.6	67.5
Opacity, %ISO	81.9	81.4	82.2	81.4	81.9	81.9
Scattering coefficient, m^2/kg	37.2	36.3	37.7	35.3	35.3	37.2
Yellowness	7.75	7.75	7.48	7.67	7.63	7.69
L*	94.4	94.2	94.4	94.4	94.3	94.3
a*	-0.02	0.03	0.00	-0.01	-0.04	-0.04
b*	4.08	4.05	3.83	4.03	4.02	4.05

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS + AKD + Talc, 270 kg/t – make-up to 0.33% cy + CPAM, 200 g/t

Table 130: Pretreatment of talc with amphoteric strength additive and its addition in MHB pulp

Talc addition, %	27	27	27	27	27	27
AS in filler, kg/t of filler	0	0	1.4	1.4	2.8	7.0
AS in wet-end, kg/t of pulp	0	5	0	4.6	4.2	3.1
Total AS, kg/t of pulp	0	5	0.4	5	5	5
Retained ash, %	18.3	18.6	18.8	19.1	18.6	18.0
FPAR, %	84.7	87.0	87.4	88.8	86.1	83.3
CSF, ml	570	570	575	630	567	555
Streaming potential, mV	-206	-211	-241	-224	-217	-222
Charge demand, µeq/l	4.7	4.9	5.1	6.7	7.1	7.1
Zeta potential, mV	-19.7	-19.0	-19.2	-18.9	-18.6	-18.7
Conductivity, mS	0.456	0.451	0.443	0.432	0.440	0.448
Bulk, cc/g	1.25	1.24	1.25	1.25	1.27	1.26
Breaking length, m	3727	4315	4061	4050	4338	4181
Burst index, kN/g	2.54	2.83	2.60	2.98	3.07	2.98
Tear index, mNm^2/g	6.30	6.41	6.27	6.12	6.12	6.39
Bending stiffness, mNm	0.145	0.155	0.161	0.166	0.155	0.154
Double fold, no.	20	24	19	21	30	19
ZD tensile strength, kPa	701	663	690	712	704	710
Air permeance, Gurley s	15.1	15.2	17.5	16.3	15.3	16.8
Bendtsen roughness, ml/min	99	97	95	97	95	87
Brightness, %ISO	81.6	81.0	81.4	81.5	81.5	81.7
CIE whiteness	67.6	66.9	68.2	68.1	67.8	68.1
Opacity, %ISO	81.9	81.4	81.4	81.8	82.0	81.8
Scattering coefficient, m^2/kg	37.2	36.3	35.9	36.3	35.8	35.9
Yellowness	7.75	7.86	7.42	7.45	7.57	7.53
L*	94.4	94.2	94.4	94.4	94.4	94.4
a*	-0.02	0.00	-0.13	-0.09	-0.09	-0.07
b*	4.08	4.12	3.95	3.95	4.01	3.99

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS + AKD + Talc, 270 kg/t – make-up to 0.33% cy + CPAM, 200 g/t

Table 131: Pretreatment of talc with CPAM and its addition in MHB pulp

Talc addition, %	27	27	27	27	27	27
CS in wet-end, kg/t of pulp	0	5	0	5	5	5
CPAM in filler, g/t of filler	0	0	26	26	52	104
CPAM in wet-end, g/t of pulp	200	200	193	193	186	172
Total CPAM, g/t of pulp	200	200	200	200	200	200
Retained ash, %	18.3	17.4	18.8	18.3	18.6	19.3
FPAR, %	84.7	81.9	87.4	86.1	87.5	90.8
CSF, ml	570	540	510	540	545	540
Streaming potential, mV	-206	-192	-241	-224	-217	-222
Charge demand, µeq/l	4.7	7.7	5.1	6.7	7.1	7.1
Zeta potential, mV	-19.7	-19.3	18.8	-19.3	-19.0	-18.6
Conductivity, mS	0.456	0.398	0.443	0.432	0.440	0.448
Bulk, cc/g	1.25	1.25	1.26	1.26	1.24	1.26
Breaking length, m	3727	4196	4139	4270	4177	3916
Burst index, kN/g	2.54	2.71	2.51	3.12	3.04	2.99
Tear index, mNm^2/g	6.30	6.56	6.14	6.48	6.32	6.46
Bending stiffness, mNm	0.145	0.160	0.178	0.163	0.150	0.146
Double fold, no.	20	26	19	37	27	35
ZD tensile strength, kPa	701	720	693	675	753	712
Air permeance, Gurley s	15.1	15.7	15.9	14.4	17.2	14.5
Bendtsen roughness, ml/min	99	93	98	98	97	99
Brightness, %ISO	81.6	81.1	81.3	81.2	81.6	81.2
CIE whiteness	67.6	67.3	67.1	66.6	67.5	67.2
Opacity, %ISO	81.9	81.4	81.0	81.9	81.6	81.1
Scattering coefficient, m^2/kg	37.2	36.3	37.2	36.1	35.8	35.5
Yellowness	7.75	7.75	7.84	8.09	7.75	7.80
L*	94.4	94.2	94.3	94.4	94.4	94.3
a*	-0.02	0.03	-0.06	-0.04	-0.05	-0.03
b*	4.08	4.05	4.15	4.27	4.09	4.11

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS + AKD + Talc, 270 kg/t – make-up to 0.33% cy + CPAM

Table 132: Charge analysis of the pretreated GCC (20% w/v) using different doses of cationic strength additive

CS dose		Charge, mV	Charge demand, µeq/g
% of 5 kg/t	kg/t filler		
0	0	+146	3.1
20	2.6	+218	3.6
50	6.6	+169	4.7

Table 133: Charge analysis of the pretreated GCC (20% w/v) using different doses of amphoteric strength additive

AS dose		Charge, mV	Charge demand, µeq/g
% of 5 kg/t	kg/t filler		
0	0	+146	3.1
10	1.3	+172	2.0
20	2.6	+184	3.5

Table 134: Pretreatment of GCC with cationic strength additive and its addition in MHB pulp

GCC addition, %	48	48	67	48	48	48
CS in filler, kg/t of filler	0	0	0	2.6	2.6	6.6
CS in wet-end, kg/t of pulp	0	5	5	0	3.7	1.8
Total CS, kg/t of pulp	0	5	5	1.3	5	5
Retained ash, %	17.9	18.0	21.0	20.5	21.5	21.6
FPAR, %	55.2	55.5	52.4	63.3	66.3	66.6
CSF, ml	519	520	540	535	542	540
Streaming potential, mV	-228	-208	-198	-209	-195	-224
Charge demand, µeq/l	12.7	10.4	9.8	11.7	10.0	10.9
Zeta potential, mV	-13.8	-12.3	-11.6	-13.6	-12.7	-12.4
Conductivity, mS	0.442	0.441	0.431	0.454	0.437	0.464
Bulk, cc/g	1.38	1.35	1.36	1.34	1.37	1.33
Breaking length, m	3524	4206	3615	3279	3474	3362
Burst index, kN/g	2.06	2.62	2.08	1.93	2.11	2.19
Tear index, mNm^2/g	5.85	5.98	5.62	5.65	5.94	5.69
Bending stiffness, mNm	0.203	0.185	0.154	0.179	0.150	0.139
Double fold, no.	6	13	8	7	7	9
ZD tensile strength, kPa	676	723	656	618	656	641
Wax pick no.	7	8	9	7	8	8
Air permeance, Gurley s	8.6	9.9	8.6	10.5	8.0	8.8
Bendtsen roughness, ml/min	122	109	115	116	133	128
Brightness, %ISO	83.8	83.2	84.2	83.6	83.9	83.6
CIE whiteness	71.7	70.3	72.1	71.5	71.8	71.8
Opacity, %ISO	87.7	86.7	87.3	87.6	87.1	87.6
Scattering coefficient, m^2/kg	53.8	50.3	54.3	52.3	52.7	52.6
Yellowness	7.05	7.46	7.03	7.04	6.97	6.98
L*	95.3	95.2	95.5	95.3	95.3	95.3
a*	0.06	0.02	0.01	0.04	0.02	0.04
b*	3.71	3.94	3.72	3.71	3.67	3.67

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

Table 135: Pretreatment of GCC with amphoteric strength additive and its addition in MHB pulp

GCC addition, %	48	48	67	48	48	48
AS in filler, kg/t of filler	0	0	0	1.3	1.3	2.6
AS in wet-end, kg/t of pulp	0	5	5	0	4.4	3.7
Total AS, kg/t of pulp	0	5	5	5	5	5
Retained ash, %	17.9	17.8	23.1	19.8	24.1	24.4
FPAR, %	55.2	54.9	57.6	61.1	74.4	75.3
CSF, ml	519	528	563	538	595	600
Streaming potential, mV	-228	-213	-207	-221	-202	-178
Charge demand, µeq/l	12.7	9.6	6.0	9.4	8.2	6.7
Zeta potential, mV	-13.8	-10.4	-7.9	-11.2	-9.8	-7.0
Conductivity, mS	0.442	0.501	0.581	0.498	0.470	0.469
Bulk, cc/g	1.38	1.37	1.39	1.37	1.34	1.33
Breaking length, m	3524	3698	3197	3612	3274	3355
Burst index, kN/g	2.06	2.37	1.72	2.05	2.09	2.32
Tear index, mNm^2/g	5.85	6.28	5.39	6.05	5.84	5.84
Bending stiffness, mNm	0.203	0.156	0.167	0.144	0.159	0.136
Double fold, no.	6	13	6	9	9	11
ZD tensile strength, kPa	676	650	-	653	628	666
Wax pick no.	7	10	-	8	9	10
Air permeance, Gurley s	8.6	9.5	7.8	11.5	9.5	10.3
Bendtsen roughness, ml/min	122	113	118	131	123	145
Brightness, %ISO	83.8	83.5	84.8	84.0	83.9	83.6
CIE whiteness	71.7	70.9	73.2	72.2	71.9	71.8
Opacity, %ISO	87.7	86.8	88.6	88.1	88.6	88.2
Scattering coefficient, m^2/kg	53.8	52.3	58.3	55.3	55.0	53.4
Yellowness	7.05	7.39	6.66	6.81	6.92	6.94
L*	95.3	95.3	95.6	95.3	95.3	95.2
a*	0.06	0.00	0.07	0.04	0.04	0.05
b*	3.71	3.91	3.50	3.58	3.64	3.64

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

Table 136: Charge analysis of the pretreated PCC (20% w/v) using different doses of cationic strength additive

CS dose		Charge, mV	Charge demand, µeq/g
% of 5 kg/t	kg/t filler		
0	0	+43	1.8
20	2.6	+52	2.6
50	6.6	+101	4.7

Table 137: Charge analysis of the pretreated PCC (20% w/v) using different doses of amphoteric strength additive

AS dose		Charge, mV	Charge demand, µeq/g
% of 5 kg/t	kg/t filler		
0	0	+43	1.8
10	1.3	+54	3.9

Table 138: Charge analysis of the pretreated PCC (20% w/v) using different doses of APAM

APAM dose		Charge, mV	Charge demand, µeq/g
% of 80 g/t	g/t filler		
0	0	+43	1.8
50	132	-559	0.3

Table 139: Pretreatment of PCC with cationic strength additive and its addition in MHB pulp

PCC addition, %	36	36	44	36	36
CS in filler, kg/t of filler	0	0	0	2.6	2.6
CS in wet-end, kg/t of pulp	0	5	5	0	4.1
Total CS, kg/t of pulp	0	5	5	0.9	5
Retained ash, %	17.1	17.5	22.6	20.5	20.6
FPAR, %	64.6	66.1	74.1	77.4	77.8
CSF, ml	451	463	483	458	458
Streaming potential, mV	-211	-289	-210	-286	-278
Charge demand, µeq/l	6.8	14.0	10.7	14.2	13.8
Zeta potential, mV	-13.6	-17.5	-15.6	-17.3	-16.9
Conductivity, mS	0.472	0.464	0.472	0.472	0.461
Bulk, cc/g	1.50	1.50	1.50	1.52	1.49
Breaking length, m	2835	3780	3105	2986	3411
Burst index, kN/g	1.75	2.33	1.95	1.96	2.11
Tear index, mNm^2/g	6.10	6.98	6.28	5.85	6.29
Bending stiffness, mNm	0.182	0.190	0.207	0.210	0.220
Double fold, no.	6	10	8	9	10
ZD tensile strength, kPa	600	674	671	673	633
Air permeance, Gurley s	7.4	8.6	8.9	7.6	9.6
Bendtsen roughness, ml/min	141	160	140	173	144
Brightness, %ISO	84.4	83.8	84.8	84.1	84.4
CIE whiteness	72.4	71.5	74.0	73.2	73.3
Opacity, %ISO	89.3	88.7	91.1	90.7	90.3
Scattering coefficient, m^2/kg	60.7	56.9	64.9	62.3	60.5
Yellowness	6.87	7.21	6.42	6.55	6.53
L*	95.5	95.5	95.7	95.4	95.5
a*	0.02	0.03	0.05	0.09	0.08
b*	3.63	3.81	3.38	3.43	3.42

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

Table 140: Pretreatment of PCC with amphoteric strength additive and its addition in MHB pulp

PCC addition, %	36	36	44	36	36
AS in filler, kg/t of filler	0	0	0	1.3	1.3
AS in wet-end, kg/t of pulp	0	5	5	0	4.5
Total AS, kg/t of pulp	0	5	5	0.5	5
Retained ash, %	17.1	18.9	22.5	21.5	22.1
FPAR, %	64.6	71.4	73.7	81.2	83.4
CSF, ml	451	468	492	518	522
Streaming potential, mV	-211	-203	-178	-209	-198
Charge demand, µeq/l	6.8	5.9	5.4	6.1	5.5
Zeta potential, mV	-13.6	-12.2	-11.1	-11.1	-11.3
Conductivity, mS	0.472	0.463	0.455	0.450	0.462
Bulk, cc/g	1.50	1.49	1.52	1.51	1.51
Breaking length, m	2835	3306	3007	3282	3324
Burst index, kN/g	1.75	1.96	1.76	1.91	2.02
Tear index, mNm^2/g	6.10	6.24	5.96	6.57	6.61
Bending stiffness, mNm	0.182	0.210	0.171	0.167	0.172
Double fold, no.	6	9	7	10	10
ZD tensile strength, kPa	600	687	657	661	659
Air permeance, Gurley s	7.4	6.8	6.8	6.7	6.6
Bendtsen roughness, ml/min	141	150	159	162	180
Brightness, %ISO	84.4	84.4	85.0	84.1	84.5
CIE whiteness	72.4	72.5	73.6	72.8	73.0
Opacity, %ISO	89.3	88.7	89.7	90.4	90.6
Scattering coefficient, m^2/kg	60.7	61.9	65.2	68.6	65.1
Yellowness	6.87	6.83	6.6	6.67	6.64
L*	95.5	95.5	95.7	95.4	95.5
a*	0.02	0.07	0.05	0.05	0.06
b*	3.63	3.59	3.48	3.50	3.49

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

Table 141: Pretreatment of PCC with APAM and its addition in MHB pulp

Talc addition, %	36	36	44	36	36
CS in wet-end, kg/t of pulp	0	5	5	5	5
APAM in filler, g/t of filler	0	0	0	22	56
APAM in wet-end, g/t of pulp	80	80	80	72	60
Total APAM, g/t of pulp	80	80	80	80	80
Retained ash, %	17.1	17.5	22.6	21.4	20.4
FPAR, %	64.6	66.1	74.1	80.8	77.1
CSF, ml	451	463	483	492	496
Streaming potential, mV	-211	-289	-210	-282	-286
Charge demand, µeq/l	6.8	14.0	10.7	13.8	14.2
Zeta potential, mV	-13.6	-17.5	-15.6	-17.6	-17.2
Conductivity, mS	0.472	0.464	0.472	0.462	0.461
Bulk, cc/g	1.50	1.50	1.50	1.51	1.49
Breaking length, m	2835	3780	3105	3159	3252
Burst index, kN/g	1.75	2.33	1.95	2.06	1.89
Tear index, mNm^2/g	6.10	6.98	6.28	6.97	6.52
Bending stiffness, mNm	0.182	0.190	0.207	0.156	0.154
Double fold, no.	6	10	8	9	8
ZD tensile strength, kPa	600	674	671	612	596
Air permeance, Gurley s	7.4	8.6	8.9	6.1	6.6
Bendtsen roughness, ml/min	141	160	140	163	161
Brightness, %ISO	84.4	83.8	84.8	84.5	84.6
CIE whiteness	72.4	71.5	74.0	73.4	73.5
Opacity, %ISO	89.3	88.7	91.1	89.5	89.1
Scattering coefficient, m^2/kg	60.7	56.9	64.9	62.2	60.9
Yellowness	6.87	7.21	6.42	6.64	6.64
L*	95.5	95.5	95.7	95.5	95.5
a*	0.02	0.03	0.05	0.06	0.06
b*	3.63	3.81	3.38	3.49	3.49

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS + AKD + PCC – make-up to 0.33% cy + APAM

Table 142: Pretreatment of GCC with cationic strength additive and its addition in BWS pulp

GCC addition, %	29	29	35	40	29	29	29
CS in filler, kg/t of filler	0	0	0	0	1.3	2.6	2.6
CS in wet-end, kg/t of pulp	0	5	5	5	4.6	0	4.2
Total CS, kg/t of pulp	0	5	5	5	5	0.8	5
Retained ash, %	18.5	18.3	20.7	23.1	19.3	19.3	20.5
FPAR, %	88.2	72.5	72.2	73.8	76.9	76.9	82.3
CSF, ml	435	432	440	448	436	435	441
Streaming potential, mV	-140	-181	-190	-185	-183	-198	-188
Charge demand, µeq/l	7.9	5.8	5.5	5.1	5.6	6.6	5.7
Zeta potential, mV	6.8	-8.1	-7.9	-7.6	-8.2	-8.8	-8.0
Conductivity, mS	0.542	0.481	0.487	0.485	0.486	0.496	0.485
Bulk, cc/g	1.36	1.35	1.36	1.34	1.34	1.36	1.34
Breaking length, m	2375	3001	2901	2797	2935	2495	2739
Burst index, kN/g	1.75	1.98	1.90	1.67	1.95	1.88	1.90
Tear index, mNm^2/g	4.29	4.46	4.33	3.95	3.90	4.15	4.21
Bending stiffness, mNm	0.099	0.120	0.121	0.114	0.105	0.112	0.107
Double fold, no.	7	8	7	8	9	7	9
ZD tensile strength, kPa	589	650	634	594	623	604	622
Wax pick no.	8	9	8	8	7	7	8
Air permeance, Gurley s	39.9	39.7	38.9	38.1	40.6	42.8	46.4
Bendtsen roughness, ml/min	128	132	132	127	129	137	129
Brightness, %ISO	83.1	83.0	83.4	83.5	82.7	82.7	82.3
CIE whiteness	71.7	71.4	71.9	72.6	71.0	71.3	70.7
Opacity, %ISO	87.6	87.5	88.4	88.3	87.5	87.4	87.1
Scattering coefficient, m^2/kg	53.1	52.0	54.4	55.0	51.2	51.1	49.3
Yellowness	6.50	6.61	6.61	6.35	6.76	6.58	6.66
L*	94.9	94.9	95.1	95.1	94.8	94.8	94.6
a*	-0.04	-0.07	-0.07	-0.08	-0.03	-0.04	-0.05
b*	3.44	3.51	3.51	3.38	3.57	3.47	3.52

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

Table 143: Pretreatment of GCC with amphoteric strength additive and its addition in BWS pulp

GCC addition, %	29	29	35	40	29	29	35
AS in filler, kg/t of filler	0	0	0	0	1.3	1.3	2.6
AS in wet-end, kg/t of pulp	0	5	5	5	0	4.6	4.2
Total AS, kg/t of pulp	0	5	5	5	0.4	5	5
Retained ash, %	18.5	19.4	20.9	23	18.9	20.7	23.8
FPAR, %	88.2	77.2	72.9	73.4	75.2	82.4	84.2
CSF, ml	435	450	456	462	448	444	469
Streaming potential, mV	-140	-130	-125	-118	-142	-135	-120
Charge demand, µeq/l	7.9	7.1	6.9	6.1	7.8	7.2	6.4
Zeta potential, mV	6.8	-5.4	-5.2	5.1	-6.2	-5.6	-5.4
Conductivity, mS	0.542	0.510	0.498	0.499	0.528	0.518	0.505
Bulk, cc/g	1.36	1.33	1.34	1.32	1.35	1.31	1.31
Breaking length, m	2375	2853	2793	2549	3014	3038	2900
Burst index, kN/g	1.75	2.01	1.94	1.63	1.96	2.06	1.87
Tear index, mNm^2/g	4.29	4.19	4.02	3.88	4.12	4.41	3.82
Bending stiffness, mNm	0.099	0.136	0.118	0.104	0.116	0.120	0.113
Double fold, no.	7	12	10	7	8	12	10
ZD tensile strength, kPa	589	633	644	569	601	624	642
Wax pick no.	8	10	9	7	8	9	9
Air permeance, Gurley s	39.9	27.6	29.2	29.8	26.6	22.2	26.0
Bendtsen roughness, ml/min	128	129	122	132	126	117	109
Brightness, %ISO	83.1	83.2	83.6	84.1	83.4	82.4	83.0
CIE whiteness	71.7	71.7	72.2	73.1	71.8	70.3	71.6
Opacity, %ISO	87.6	87.1	87.6	88.4	87.5	86.7	87.3
Scattering coefficient, m^2/kg	53.1	49.4	52.3	55.0	51.2	46.1	48.5
Yellowness	6.50	6.44	6.37	6.99	6.38	6.64	6.38
L*	94.9	94.8	94.9	95.0	94.7	94.4	94.7
a*	-0.04	0.01	-0.02	-0.02	-0.01	0.05	0.02
b*	3.44	3.38	3.36	3.15	3.35	3.46	3.34

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS + AKD + GCC – make-up to 0.33% cy + CPAM, 200 g/t

Table 144: Pretreatment of PCC with cationic strength additive and its addition in BWS pulp

PCC addition, %	29	29	37	29	29
CS in filler, kg/t of filler	0	0	0	2.6	2.6
CS in wet-end, kg/t of pulp	0	5	5	0	4.2
Total CS, kg/t of pulp	0	5	5	0.9	5
Retained ash, %	18.1	18.4	21.6	19.6	20.4
FPAR, %	60.8	73.2	72.6	65.8	68.5
CSF, ml	443	445	454	450	449
Streaming potential, mV	-127	-108	-112	-119	-111
Charge demand, µeq/l	8.9	6.1	6.4	7.2	6.2
Zeta potential, mV	-10.9	-9.3	9.7	-9.5	-9.2
Conductivity, mS	0.471	0.428	0.438	0.442	0.431
Bulk, cc/g	1.46	1.45	1.48	1.45	1.45
Breaking length, m	2618	2596	2468	2721	2989
Burst index, kN/g	1.64	1.84	1.68	1.76	2.03
Tear index, mNm^2/g	3.93	4.62	4.45	4.04	4.25
Bending stiffness, mNm	0.139	0.130	0.124	0.132	0.140
Double fold, no.	7	7	6	8	10
ZD tensile strength, kPa	546	586	553	538	602
Wax pick no.	8	9	9	8	9
Air permeance, Gurley s	26.3	26.8	21.5	28.0	28.6
Bendtsen roughness, ml/min	148	151	151	141	138
Brightness, %ISO	84.4	84.2	84.7	84.1	84.3
CIE whiteness	73.2	73.5	74.2	72.6	72.9
Opacity, %ISO	87.9	88.6	88.9	87.8	88.0
Scattering coefficient, m^2/kg	53.7	54.0	58.5	53.9	53.9
Yellowness	6.28	6.13	5.98	6.44	6.35
L*	95.2	95.2	95.4	95.2	95.2
a*	-0.05	0.04	0.01	-0.07	-0.08
b*	3.33	3.21	3.16	3.44	3.38

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + CS + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

Table 145: Pretreatment of PCC with amphoteric strength additive and its addition in BWS pulp

PCC addition, %	29	29	37	42	37	37
AS in filler, kg/t of filler	0	0	0	0	1.3	1.3
AS in wet-end, kg/t of pulp	0	5	5	5	0	4.5
Total AS, kg/t of pulp	0	5	5	5	0.5	5
Retained ash, %	18.1	19.0	21.7	23.9	22.8	23.1
FPAR, %	60.8	75.6	72.9	73.9	76.6	77.6
CSF, ml	443	422	432	439	437	441
Streaming potential, mV	-127	-98	-122	-124	-121	-126
Charge demand, µeq/l	8.9	5.8	6.0	6.2	7.4	6.2
Zeta potential, mV	-10.9	-7.8	-8.2	8.5	-9.2	-8.4
Conductivity, mS	0.471	0.418	0.428	0.431	0.436	0.431
Bulk, cc/g	1.46	1.45	1.48	1.47	1.50	1.47
Breaking length, m	2618	2873	2501	2451	2476	2497
Burst index, kN/g	1.64	1.93	1.70	1.68	1.63	1.78
Tear index, mNm^2/g	3.93	4.27	4.10	3.95	4.52	4.64
Bending stiffness, mNm	0.139	0.128	0.146	0.128	0.129	0.124
Double fold, no.	7	7	6	6	5	6
ZD tensile strength, kPa	546	566	540	534	541	545
Wax pick no.	8	7	7	6	6	6
Air permeance, Gurley s	26.3	28.2	23.1	21.6	21.4	21.8
Bendtsen roughness, ml/min	148	163	187	138	166	159
Brightness, %ISO	84.4	83.2	83.9	84.2	84.1	83.8
CIE whiteness	73.2	71.7	73.4	74.0	72.4	72.7
Opacity, %ISO	87.9	88.6	89.9	90.0	88.7	89.8
Scattering coefficient, m^2/kg	53.7	55.1	59.6	62.4	59.3	60.5
Yellowness	6.28	6.70	6.25	6.10	6.69	6.54
L*	95.2	95.0	95.3	95.4	95.4	95.3
a*	-0.05	0.02	0.02	0.03	-0.06	-0.02
b*	3.33	3.52	3.29	3.20	3.56	3.46

Sequence: Pulp, 30 g o.d. (1.0% cy) + CFA, 200 g/t + AS + AKD + PCC – make-up to 0.33% cy + APAM, 80 g/t

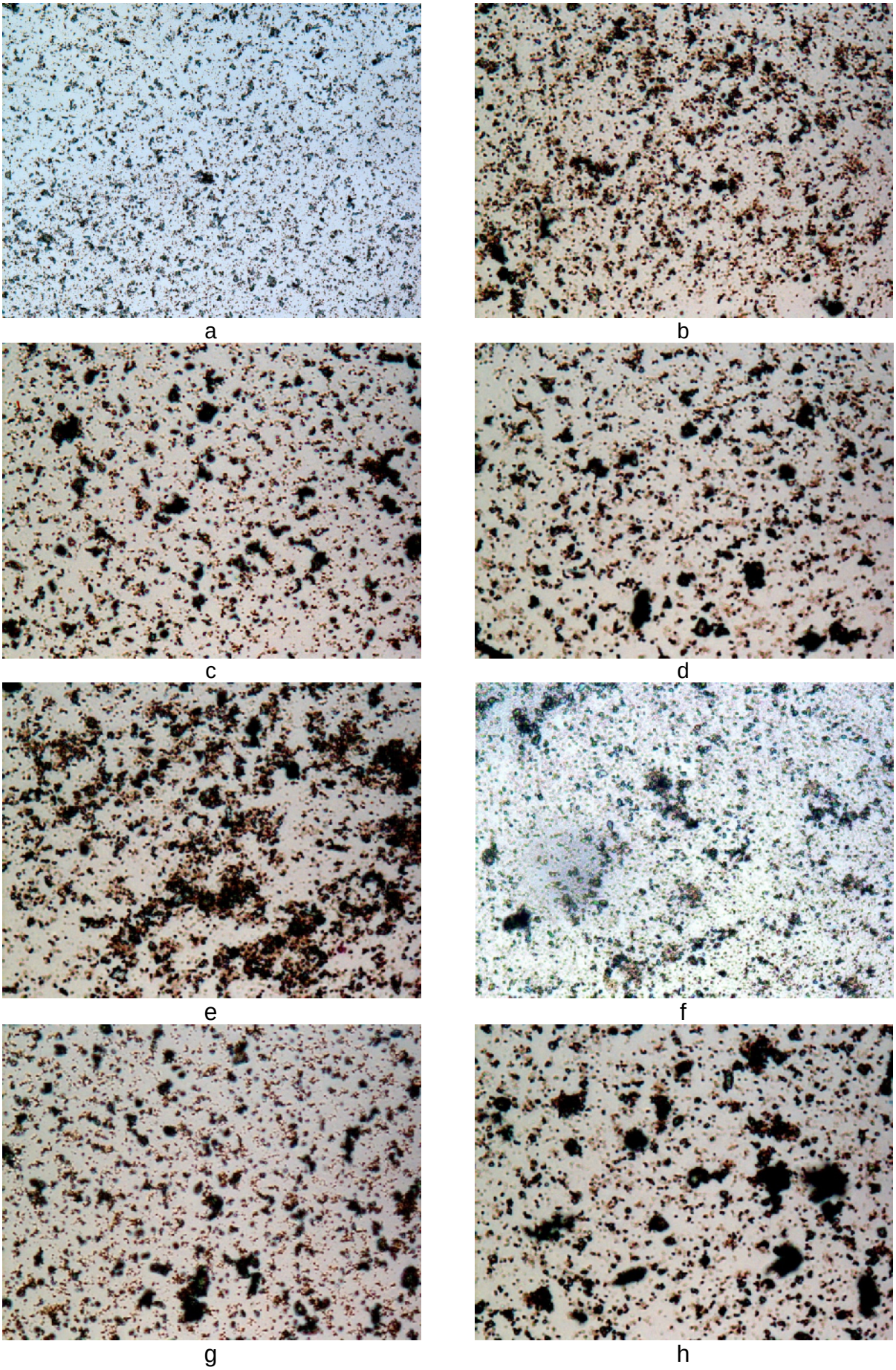

Figure 140. Talc filler, a) without pretreatment, and pretreated talc with CS, b) 1.4 kg/t, c) 2.8 kg/t, with AS, d) 1.4 kg/t, e) 2.8 kg/t, with CPAM, f) 25.8 g/t, g) 51.8 g/t, h) 103.7 g/t

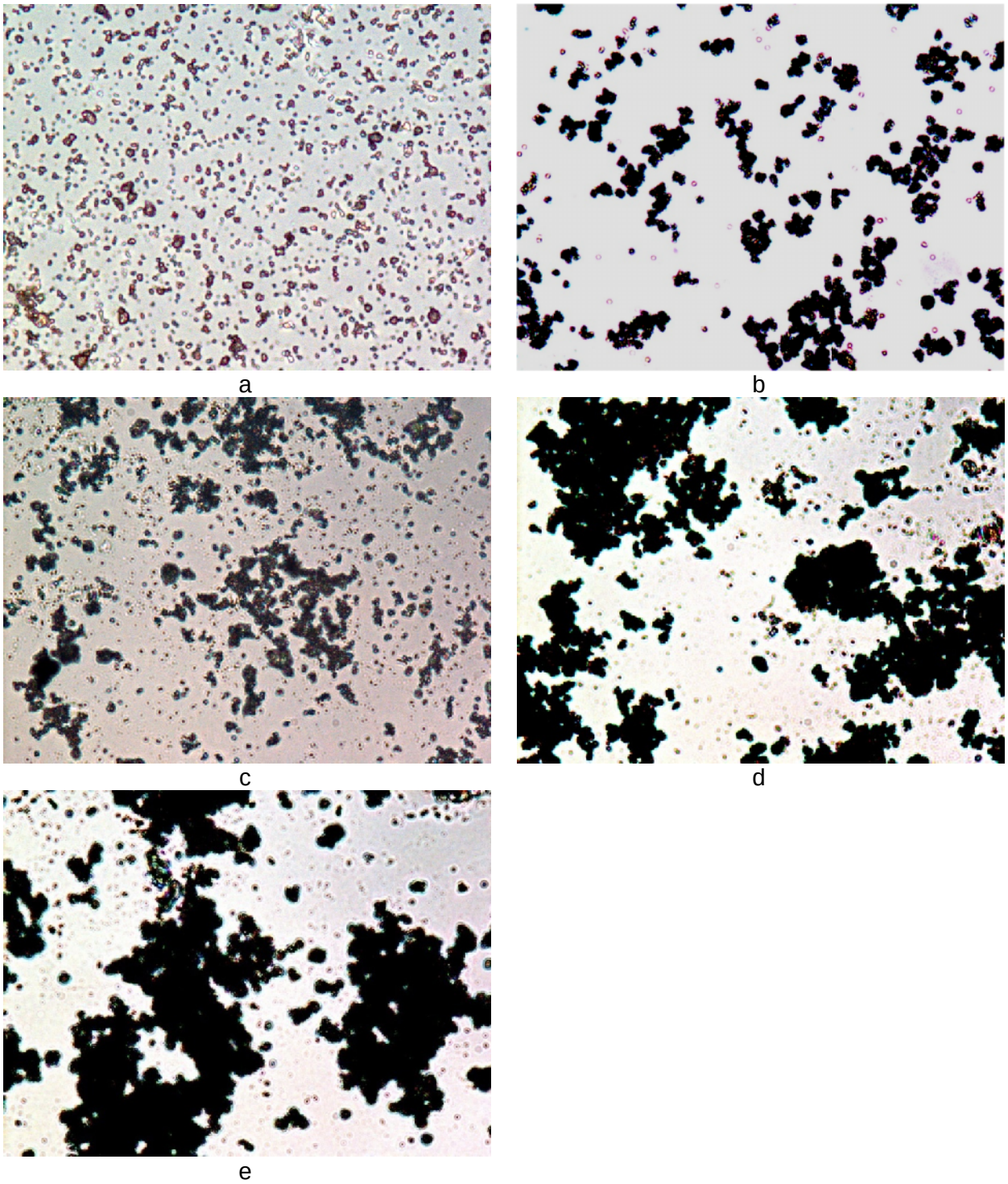

Figure 141. GCC filler, a) without pretreatment, and pretreated GCC with CS, b) 2.6 kg/t, with AS, c) 1.3 kg/t, with CPAM, d) 21 g/t, e) 42 g/t

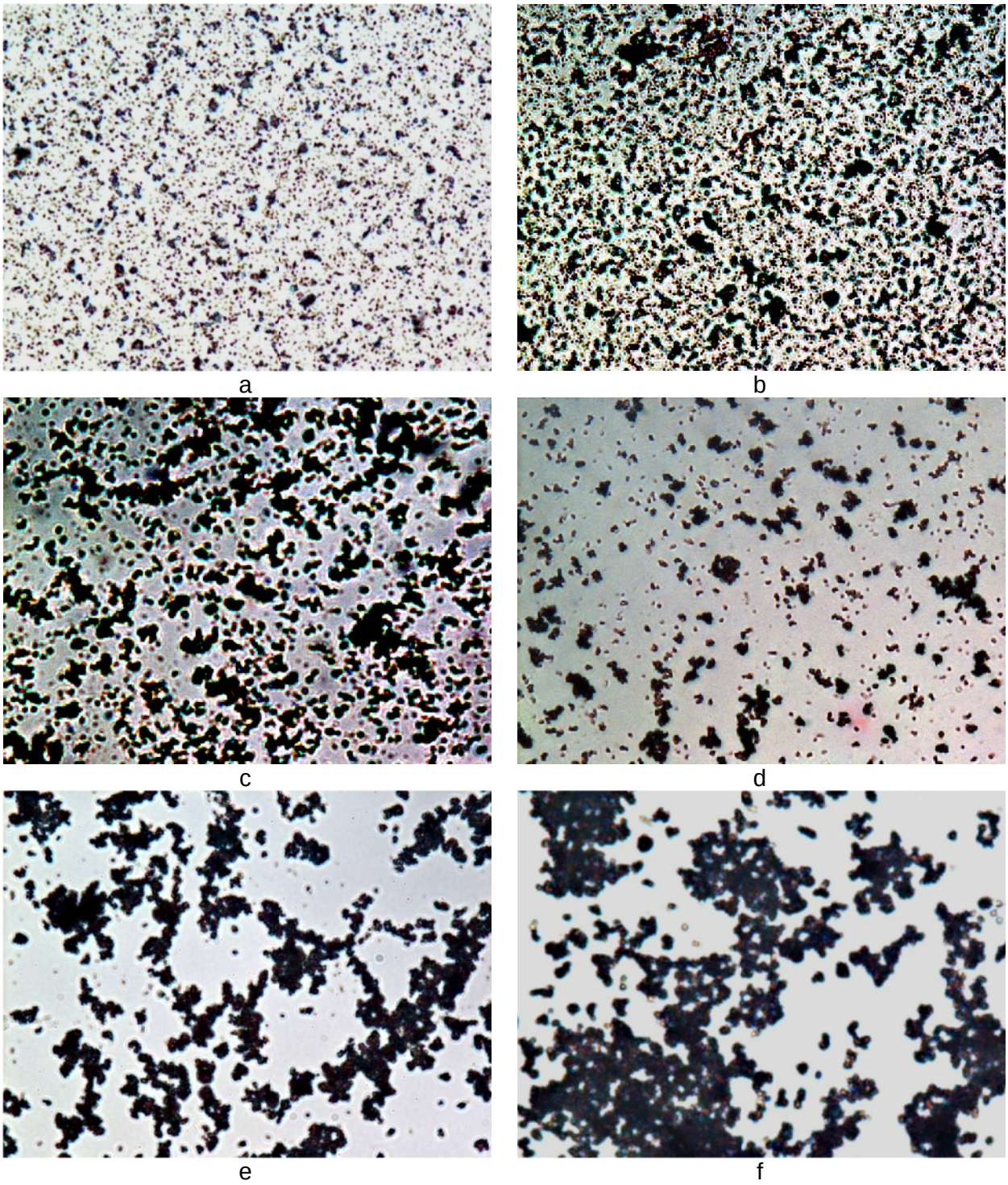

Figure 142. PCC filler, a) without pretreatment, and pretreated PCC with CS, b) 2.6 kg/t, c) 6.5 kg/t, with AS, d) 1.3 kg/t, with CPAM, e) 22 g/t, f) 56 g/t

CONCLUSIONS

The average fiber length and width of bleached recycled (BRC) pulp were the highest among all pulps. These properties were comparable for bleached mixed hardwood (MHW), bleached mixed hardwood blended with bamboo (MHB) and bleached wheat straw (BWS) pulps, and were the lowest in case of bleached bagasse (BBS) pulp. The coarseness of MHW pulp was the highest followed by BRC, BWS, BBS and MHB pulp. The fines were the highest in BWS pulp followed by BBS, MHW, BRC and MHB pulp. Cationic charge demand of BBS pulp was the highest among all pulp furnishes. The brightness of MHW pulp was the highest followed by MHB, BBS, BRC and BWS. The air permanence of handsheets prepared by agro residue furnish was higher than that of hardwood furnishes.

The optical properties of PCC were the highest among all fillers. GCC was the finest followed by PCC and talc. PCC was scalenohedral and GCC and talc were monoclinic in crystalline structure. GCC and PCC were cationic in nature whereas talc was anionic. Increase in refining of pulp was congenial for higher ash content and FPAR of fillers though the increment depended upon the ionic behavior, particle size distribution and shape of filler, and the ionic and morphological behavior of papermaking slurry. The FPAR in case of talc and PCC were good even without addition of wet-end chemicals. In case of GCC, it was quite low without addition of wet-end chemicals but with optimized dose of wet-end chemicals, the FPAR of GCC increased from 23-31% to 53-54%.

The increase in the filler or ash content in paper decreased the strength properties and increased the optical properties of paper. The ash in paper made with bleached mixed hardwood blended with bamboo (MHB) pulp and talc filler could be increased from 15 to 18% using 10-15 kg/t dose of cationic strength additive (CS) or amphoteric strength additive (AS) and 21% using 8-10 kg/t dose of polymeric strength additive (PS) without adversely affecting paper strength. With talc as filler, PS was the most effective strength additive followed by AS and CS. The ash in paper made with MHB pulp and GCC filler could be increased from 15 to 18% using 10-15 kg/t dose of CS or AS. PS had a negative effect on filler retention and not found suitable with GCC filler. The decrease in strength properties was higher in case of PCC than that in case of talc. The bulk of paper made with PCC was much higher than that with talc. Opacity and other optical properties of paper with PCC were also superior to those with talc. The ash in paper made with MHB pulp and PCC filler could be increased from 15 to 18% using 10-15 kg/t dose of CS or 6 kg/t dose of PS and 21% using 10-15 kg/t dose of AS or 8 kg/t dose of PS. PS with PCC filler also reduced little FPAR, however, its effect on paper strength was positive. The lower tear index in case of AS and PS could be compensated by reducing degree of refining.

With bleached mixed hardwood (MHW) pulp and talc filler, the better strength additives to increase ash from 18 to 21-22% were PS (10 kg/t) and AS (15 kg/t). With GCC filler, ash could

be increased from 17 to 21% using 15 kg/t dose of CS with some improvement in breaking length. The ash could be increased further to 22% using 15 kg/t dose of AS at similar breaking length. With PCC filler, the better strength additives to increase ash from 15 to 19% were AS (15 kg/t) and CS (15 kg/t). The increased level of ash in paper at similar paper strength also improved the optical properties of paper including opacity and scattering coefficient.

The strength properties of bleached bagasse (BBS) pulp were comparatively much lower than those of MHW and MHB pulps. Air permeance of paper was comparatively higher in case of BBS pulp than hardwood pulps. The ash content in case of BBS pulp and talc filler could be increased from 17 to 22% using 10-15 kg/t dose of CS/ AS or 8-10 kg/t dose of PS without affecting strength properties. The BBS pulp might need blending of long fibers to maintain its runnability on paper machine. With PCC filler, the ash in paper could be increased from 17 to 21% using 15 kg/t dose of CS/ AS without adversely affecting strength properties. In case of GCC filler, the ash in paper could be increased from 15 to 21% using 10-15 kg/t dose of CS/ AS.

The physical properties of paper made from bleached wheat straw (BWS) pulp were comparably lower than those of hardwood pulps. The lower tear index in case of BWS pulp might affect the machine runnability negatively. The papermakers would need to blend some proportion of long fibers (hardwood, softwood) with BWS pulp to maintain few specific paper properties such as tear strength. With talc filler, the ash in paper could be increased from 15 to 19% using 15 kg/t dose of CS or 10 kg/t dose of AS without affecting the strength properties. With GCC filler, the ash in paper could be increased from 18 to 21% using 10 kg/t dose of CS/ AS and 23% using 15 kg/t dose of CS/ AS. In case of BWS and PCC filler, the ash in paper could be increased from 18 to 21% using 10 kg/t dose of CS and 23% using 15 kg/t dose of CS/ AS with little compromise in ZDTS.

The strength properties viz., breaking length and burst index in case of bleached recycled (BRC) pulp were too low as compared to hardwood and agro-residue based pulps. The tear index of BRC pulp was quite good. It would be highly desirable to blend some proportion of long fibers with BRC pulp. In case of BRC pulp and talc filler, the ash could be increased from 15 to 21% using 15 kg/t dose of CS/ AS without adversely affecting the paper strength. With GCC filler, the ash in paper could be increased from 15 to 20% using 10 kg/t dose of CS/AS and 24% using 15 kg/t dose of CS/AS. With PCC filler, the ash could be increased from 15% (reference) to 21-22% using 15 kg/t dose of CS/ AS.

The split addition of dry strength additive in filler and wet-end was congenial to the increasing ash in paper without adversely affecting the paper strength or vice-versa. A little dose of CS or AS added in filler for its pre-treatment might help in increasing the ash in paper while maintaining the paper strength. The dry strength additives were found more suitable for this purpose as compared with retention aid polymers. Moreover, the pre-treatment of GCC and PCC fillers was more useful as compared with talc; the latter has higher particle size which

might have reduced its effect on paper after pre-treatment. The loading of pre-treated talc using CS could help in further increasing the ash by 1-2% without adversely affecting the paper strength. With pre-treated GCC filler, the ash could further be increased by 2-3% using CS and 4-5% using AS with comparable strength properties. The pre-treatment of PCC filler was also effective to increase the ash in paper. It increased the ash in paper from 17 to 20% (3 points) using CS without adversely affecting the paper strength. When AS was used for the pre-treatment of PCC, the ash could be increased to 21% (4 points).

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