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The Effect of Borax-Modified Starch on Wheat Straw-Based Paper Properties

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ABSTRACT: This study was focused on the improvement of mechanical strength properties of wheat straw-based paper through modification of wet-end cationic starch with borax. Borax has been used extensively in many industrial applications for its unique physical and chemical properties. We investigated the strengthening effect of borax-modified starch (BMS) as wet-end paper strength additive on the mechanical strength properties especially the tensile strength of wheat straw-based paper. Hand-sheets made of typical wheat straw-based papermaking furnish were investigated. Experimental results showed that BMS substantially increased the strength properties. Tensile index, elongation, tensile energy absorption, and wet tensile index were increased by 17%, 23%, 20%, and 21%, respectively. A short mill trial was also conducted on papermaking machine in which the impact of BMS on wheat straw-based low grammage paper (<90 gsm) was investigated. The objective of mill trial was to reduce costly virgin softwood pulp content in wheat straw-based paper recipe. Mill trial results showed similar trends in strength properties as in case of laboratory studies. Virgin softwood pulp was reduced from 30% to 25% in papermaking furnish. Furthermore, no sheet breaks were reported during trial which often happened due to poor strength of paper web. This study strongly suggests that modification of wet-end cationic starch with borax holds a tremendous potential as wet-end strength additive. It can provide significantly improved strength properties, reduction in softwood pulp costs, and better papermaking machine performance. © 2012 Wiley Periodicals, Inc. J. Appl. Polym. Sci. 128: 3672–3677, 2013

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INTRODUCTION

Non-wood fibers especially wheat straw is a major raw material for pulp and paper industry in Asia particularly in countries like Pakistan, China, and India where there is a scarcity of wood. A dearth of forests in these countries has compelled them to utilize and develop non-wood fiber resources for papermaking. A number of paper industries, therefore, use non-wood fibrous materials like wheat straw and bagasse in various quantities to manufacture the different grades of paper and board. In this region, in comparison to wood pulp, not only is wheat straw abundantly available, it is significantly lower in cost.[1–5] Although wood undoubtedly is an excellent source of fibers and provides excellent paper and board properties in terms of strength and machine runnability, however, it is costly as compared to locally available non-wood fibers resources. Papermakers therefore strive to use as much non-wood fibers as possible to lower their dependence on imported soft and hard wood pulps.[6–9]

Wheat straw pulp is used in a very broad spectrum of paper and board grades ranging from writing, printing paper to liner, fluting, liquid packaging board, and cigarette board. Depending on the product requirements, wheat straw pulp is mixed with soft and hard wood pulps in various proportions ranging from 30% to almost 90% in certain paper and board grades.[10,11] Wheat straw fibers in comparison to wood fibers have some inherent advantages such as low refining energy and good sheet formation. However, there are some major challenges associated with this type of pulp which limits its usage in different varieties especially in papers less than 100 grams per square meter (gsm). These include lower drainage and poor web strength. Generally, lower strength properties result in lower papermaking machine speeds and performance. Therefore, the

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wheat straw-based paper making machines require longer wet-end, more drainage elements, lower press loading to avoid sheet breakages, and longer drying sections to counter the higher shrinkage of the straw fiber sheet. This overall affects the machine runnability resulting in lower production rates.[12–14]

Tensile strength is a very important property that not only affects machine runnability but also has a significant impact in the converting operations. Several approaches have been explored by papermakers to increase the mechanical strength properties of straw-based paper. Soft wood fibers (10%–50% of total papermaking furnish) are included in straw-based paper furnishes to achieve the required strength properties. Additionally, different wet end additives have been developed to enhance the strength properties of straw-based paper thereby reducing the overall wood pulp content in the recipe. Lower strength properties especially tensile strength coupled with poor drainage causes production loss due to excessive sheet breaks. Problem of drainage can adequately be countered by the use of drainage aids. However, tensile strength still remains an issue which restricts the amount of straw pulp content especially in low grammage papers (<100 gsm).[15,16]

Worldwide, the largest non-food application of starch is papermaking. It may be as high as 8% in some paper grades like photocopy paper, etc. Modified starches especially cationic and oxidized starches are most popular dry-strength and wet-strength additives. Cationic starch possesses positively charged groups bonded to starch polymer chains and combine with the anionic or negatively charged cellulosic fibers and inorganic fillers. Cationic starches along with other retention aids and internal sizing agents provide the required strength properties to the paper.[17–19] Borax has been added in starch in various applications such as in gluing to improve the overall binding properties and crosslinking. In paper and packaging industry, borax is largely used in starch and dextrin adhesives. These are used in paper bonding products, e.g., corrugated boxboards, paper board, and cartons sealing. However, little has been elucidated about application of borax in wet-end chemistry.[20,21]

In this study, wet-end cationic starch was modified with borax and this was used as wet-end strength additive to the papermaking process. Our objective was to investigate the impact of varying concentration of borax in borax-modified starch (BMS) on the tensile strength properties, tear strength, burst strength, and stiffness. This study was carried out in the laboratory using hand-sheets for analysis purposes. After laboratory studies, a mill trial was conducted to validate laboratory results. Mill trial was run on paper making machine under same condition as in laboratory studies. In the first part of mill trial, effect of BMS was studied on the mechanical strength properties of low grammage wheat straw-based paper. In second part, an attempt was made to reduce the expensive virgin wood pulp content in papermaking furnish by taking full advantage of BMS strengthening effect.

EXPERIMENTAL SECTION

Materials

Cationic starch was purchased from Rafhan Maize Products Co. Borax was provided by ICI Pakistan Ltd., (Karachi, Pakistan).

Table I. Preparation of Borax-Modified Starch

Sample	Cationic starch (wt/vol %)	Borax	
		Weight (g)	Percentage (%)
BMS-0	2	0	0
BMS-1	2	0.02	1
BMS-2	2	0.04	2
BMS-3	2	0.06	3
BMS-4	2	0.08	4
BMS-5	2	0.10	5

Bleached wheat straw pulp (BSP) with a refining degree of 35°SR was supplied by Chemical Pulp Bleaching Unit of Packages, Lahore. Bleached softwood pulp (BKP) was received from Chinook Kamloops, BC, Canada, in dried form. Rosin size, soapstone, and alum were obtained from commercial sources and used as received.

Preparation of Borax Modified Starch (BMS)

Two percent (wt/vol) solution of cationic starch was prepared. A representative experimental procedure for the preparation of 5% BMS-5 based on dry starch content is as follows; 0.1 g of borax was added in 100 mL of 2% (wt/vol) cationic starch solution and stirred for 15 min. This mixture was cooked at 90°C for 30 min with continuous stirring to prepare BMS. Similarly 1%, 2%, 3%, and 4% BMS were also prepared. Preparation detail of BMS is summarized in Table I.

Hand-Sheets Preparation and Testing

Dried BKP was repulped and refined in conical refiner to 30°SR at 3% consistency. The pulp furnish for the hand-sheets was prepared by mixing BSP and BKP in 50/50 ratio. Hand-sheets with a target basis weight of 70 gsm were formed on hand-sheet former. The hand-sheets were formulated with rosin size, alum, and soapstone. The six sets of hand-sheets, i.e., BMS-0, BMS-1, BMS-2, BMS-3, BMS-4, and BMS-5 were prepared. In all hand-sheets, the amount of BMS in pulp furnish was 1% based on oven dried weight of pulp. Hand-sheets were tested for various strength properties such as tensile index, elongation %, tensile energy absorption (TEA), wet tensile index, stiffness, tear index, and burst index. All tests were carried out as per Technical Association of the Pulp and Paper Industry (TAPPI) standard test methods.

Measurements

Tensile properties were studied by using the Lloyd instruments universal testing machine (Ametek, LRX, UK). A Teledyne Taber stiffness tester, Model V-5 150-B, was applied to measure Taber Stiffness in gram centimeters. Tear index was tested using a TMI Elmendorf tear tester. Burst index was measured by BF Perkins Mullen burst tester. Pulps were refined by an Escher Wyss laboratory conical refiner. Hand-sheets were made by using Weverk laboratory hand-sheet former. Mill trial was conducted on white paper making machine PM5, Packages. Preparation and dosing systems of Stock Preparation Plant (SPP) Packages were used to prepare BMS and pulp furnishes.

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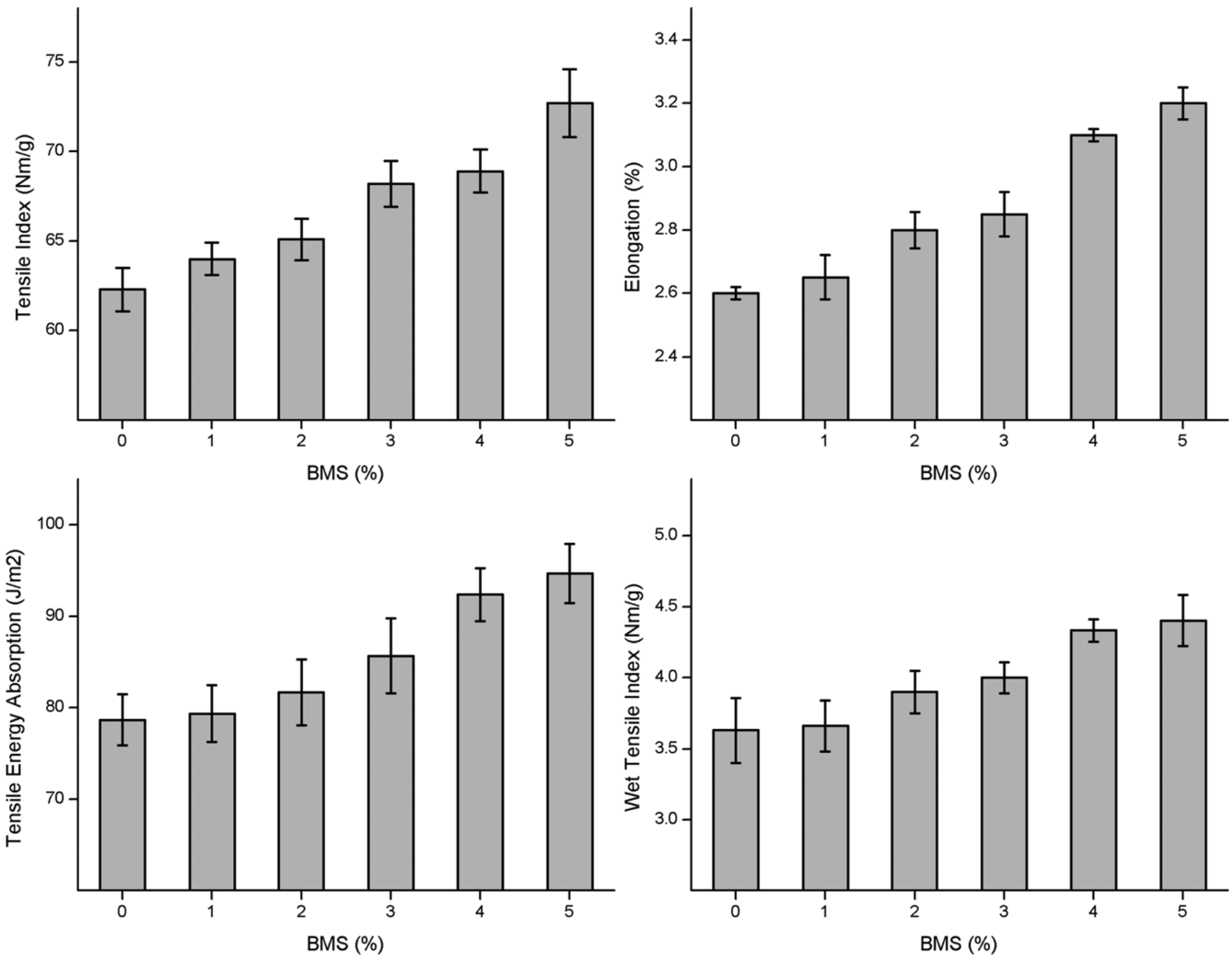
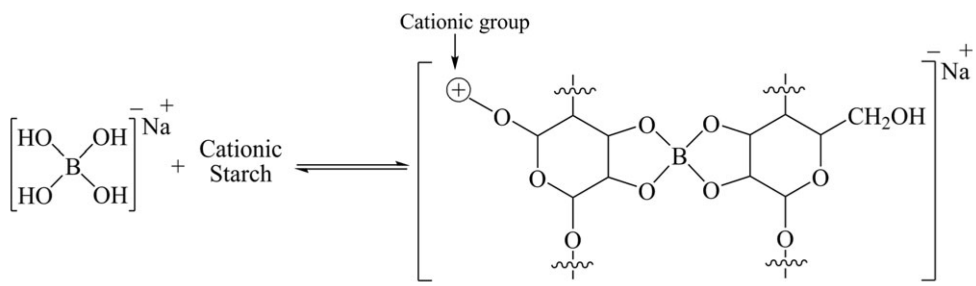


Figure 1. Tensile strength properties of hand-sheets.

RESULTS AND DISCUSSIONS

Cationic starch is most commonly used strength additive in paper chemistry at both wet-end and dry end of paper making machine. In this study, cationic starch was modified with borax and used as wet-end strength additive to compare its effect with commercially available cationic starch. The pulp furnish selected for this study was typical wheat straw-based papermaking furnish used in the preparation of white paper grades, i.e. BSP and BKP in 70/30 ratio, respectively. Initially, laboratory studies were performed and then a mill trial was carried out. Cationic starch was modified with different quantities of borax to prepare BMS solutions as given in Table I. They were added to pulp furnishes to prepare wheat straw-based low grammage paper hand-sheets. Hand-sheets were characterized to determine their tensile strength, stiffness, tear strength, and burst strength. Mill trial was carried out on white paper making machine PM-5, Packages, Lahore. In mill trial, wheat straw-based writing printing paper was prepared using BMS on the basis of laboratory studies.



Scheme 1. Formation of borax-starch complex.

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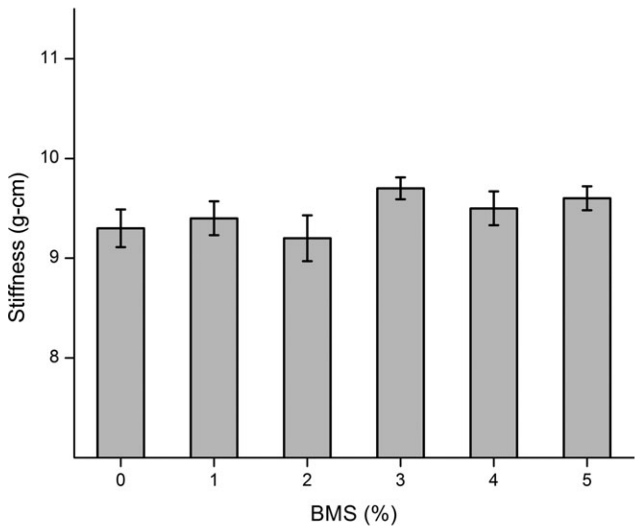

Figure 2. Stiffness of hand-sheets.

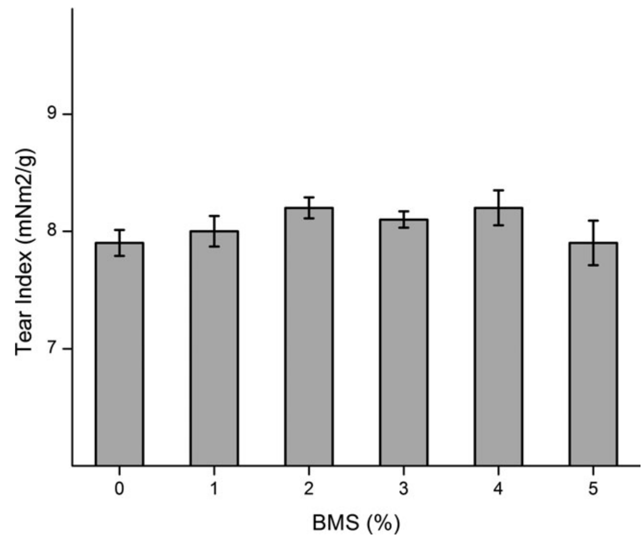

Figure 4. Tear index of hand-sheets.

Tensile properties of laboratory prepared hand-sheets are given in Figure 1. Results indicate that tensile properties, i.e., tensile index, elongation, TEA, and wet tensile index have direct correlation with the increasing concentration of borax in BMS on dry starch basis. This enhancement of tensile strength properties may be explained in terms of inter-fiber bonding reinforced by addition of BMS. Generally, strength of individual fibers, strength of fiber to fiber bonds, total bonding area, and distribution of fibers and bonds determine the strength properties of paper and board. Cationic starches are most effective strength additives because of their unique polyelectrolyte character which enhances their interaction with cellulose fibers due to proper balance of anionic and cationic charges. Adsorption of cationic starch on the surface of cellulose fibers generates more bonding sites which are stronger than original inter-fiber bonding. So, these additional bonding sites enhance the overall bonding strength [22,23] Inter-fiber bonding is generally described by the formation of hydrogen bonds of the hydroxyls of cellulose and hemicelluloses, during consolidation and drying process of paper web. These hydrogen bonds are effective over a short distance (~ 0.3 nm) between fibers and their formation is hindered by larger asperities on the fiber surface. Adhesion matrix of cationic starch fills out these asperities and thus giving rise to the new bonding areas as pointed earlier.[24–26] Cationic starch contains hydroxyl groups which are potentially capable to react with a wide variety of polyhydric materials such as polyvinyl alcohol, etc. The most probable interaction between borax and cationic starch is the formation of borax–starch complex as shown in Scheme 1. Alkali metal borates having the general structure X_2B_4O7, X_3BO_3 XBO_3, X_2HBO_3, and XH_2BO_3 (where X = Li, Na, K) usually combined with starches. The formation of these crosslinkages in cationic starch through borate ions has significant effect on the properties of cationic starch. Development of these ester linkages in cationic starch makes it more amorphous and enhances its interaction with cellulosic fibers to increase inter-fiber bonding.[27,28] Tensile properties of paper mainly depend upon the degree of inter-fiber bonding and fiber length. Results show that tensile properties increased with increase in borax contents in BMS. This can be attributed to development of more ester linkages and crosslinking in cationic starch with addition of borax which brought desirable changes in the structure of cationic starch and enhances strengthening effect of BMS.

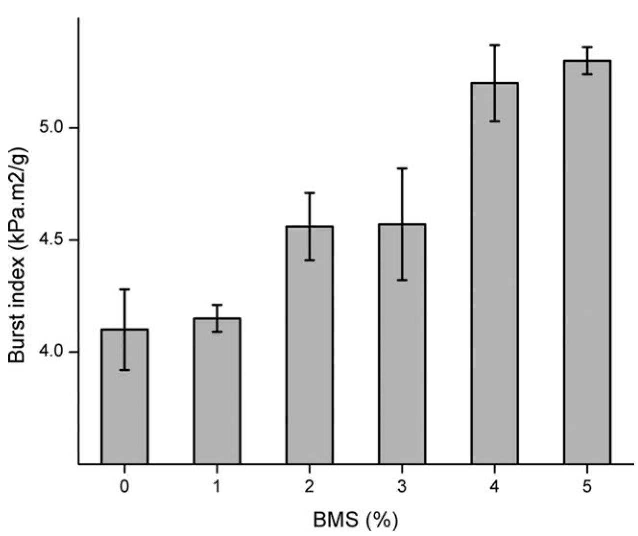

Figure 3. Burst Index of hand-sheets.

Stiffness, burst index, and tear index are given in Figures 2–4, respectively. There is no significant impact on stiffness and tear index is observed by the addition of BMS in the paper. The bursting index, however, does show a similar trend to the tensile properties which is not surprising as in general there is a correlation between the burst index and tensile strength of paper.

Mill Trial

Mill trial was conducted to validate the laboratory results. Laboratory results indicated that borax-modified cationic starch has unique ability to enhance paper strength properties when it is used as wet-end strength additive. These results also provided the basis for mill trial and a further attempt to reduce expensive

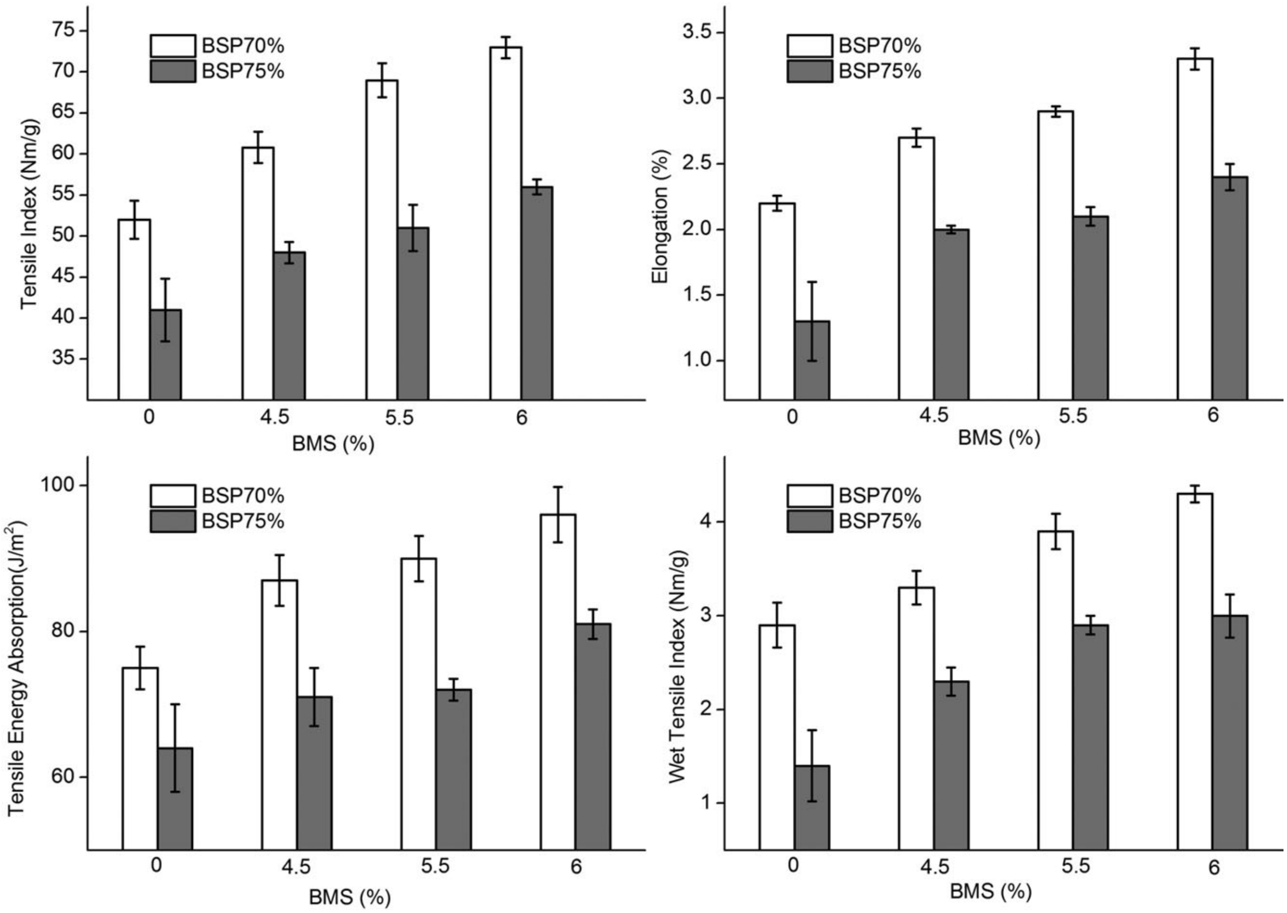

Figure 5. Tensile strength properties of mill trial paper.

virgin softwood fiber in the recipe of wheat straw-based paper and board without compromising on mechanical strength properties. Mill trial was carried out with the addition of 4.5%–6% BMS which was optimized in laboratory studies. Results of mill trial are summarized in Figures 5 and 6. These results clearly show almost identical trends as in case of laboratory results. BMS has a significant effect on tensile strength properties of paper. Papermaking machine run quite smoothly during trial. No sheet breaks were reported due to poor web strength.

In the next step of mill trial, recipe of wheat straw-based writing printing paper was changed and BSP was increased from 70% to 75% and BKP decreased from 30% to 25%. The target was cost saving by reducing BKP and maintaining desired mechanical strength properties. Trial was started with normal cationic starch and then the amount of borax modified starch was increased step by step. Tensile strength properties were dropped when BKP contents were reduced to 25%. This shows the major contribution of softwood pulp to paper strength. At the same time, increase in BSP resulted in low paper strength, poor drainage, and high energy consumption in dryer section affecting overall papermaking machine performance. The problems are possibly due to the high hemicellulose content and short fiber length in the BSP.[29] However, wet paper web started to regain strength after the addition of BMS. Tensile strength properties of paper produced from 75% BSP paper was decreased as compared to 70% BSP paper, although added amount of borax modified starch was same in both cases. Results show that tensile properties loss due to the 5% reduction of softwood fibers is compensated when higher amount (5.5%–6%) of BMS was added to pulp furnish. Meanwhile,

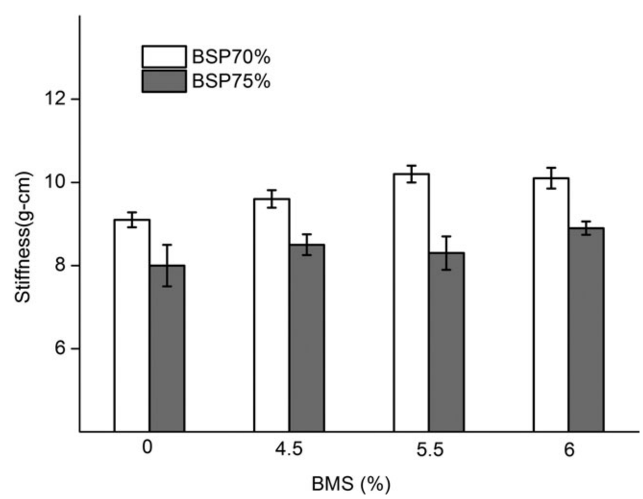

Figure 6. Stiffness of mill trial paper.

drainage, drying, and machines speed was also improved. Like laboratory results, BMS had no impact on stiffness. However, stiffness was decreased in 75% BSP paper, because long flexible fibers of softwood are critical for good stiffness.

CONCLUSIONS

This study investigated the impact of borax-modified cationic starch on the mechanical strength properties, especially properties related to tensile strength of papers using wheat straw pulp as a major ingredient. Results clearly suggest that the overall tensile properties show a significant increase while other properties are not negatively affected. The mill trials also were quite successful as the tensile properties showed a pronounced increase with the addition of BMS. A major breakthrough was achieved in cost saving mill trial. Costly BKP was partially replaced by wheat straw pulp. Paper manufactures will not only save money but also reduce their dependence on imported wood fiber. Stiffness was reduced by 6–8% in the case of high wood straw pulp content but pulp recipe and wet-end chemistry of paper can be further optimized for this. This study shows a very strong potential of using this modification of cationic starch in wheat straw-based paper and board grades which will help wheat straw-based paper makers in improving the strength properties of paper and machine runnability.

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