Impact of Nano-Silica, Cationic Polyacrylamide, and Cationic Starch on Long Fiber Utilization in Recycled Paper Production

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This study evaluated the individual and combined effects of four additives—nano-silica, cationic polyacrylamide, cationic starch, and long fibers—on paper production from recycled white pulp. Various combinations were tested with long fiber pulp (0%, 5%, 10%, and 15%) and different percentages of additives (nano-silica at 3% and 6%; cationic starch at 0.75% and 1.5%; cationic polyacrylamide at 0.07% and 0.15%). Fourteen different groups with a basis weight of 127 gsm were prepared and analyzed for their physical, mechanical, and microstructural properties. Results showed that the additives significantly impacted the properties of the paper. The highest smoothness was achieved with the combination of nano-silica and polyacrylamide, enhancing surface printability. However, the introduction of long fibers increased air resistance and decreased water absorbency, which could pose challenges in printing and machine operation. Maximum tensile and tear strength were observed in sheets with 15% long fiber pulp. Additionally, independent applications of 0.75% and 1.5% cationic starch also improved these properties. Electron microscopy revealed fewer defects in papers treated with nano-silica, though this may negatively affect water absorbency.

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Keywords: Recycled white pulp; Nano-silica; Cationic starch; Cationic polyacrylamide; Paper properties

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INTRODUCTION

The predominant material for paper production in developed countries is waste paper (Pivnenko *et al*. 2015). In recent years, the growing depletion of forest resources has heightened interest in waste paper recycling as a sustainable source of cellulosic fibers for the paper industry (Senarathna *et al*. 2023). Currently, using wood from trees in industries like papermaking is discouraged for environmental reasons, leading to a focus on cellulosic waste and residues. Products made from these recycled fibers need to compete effectively in both national and international markets with those produced from virgin pulp fibers. With approximately 59.9% of the fibers utilized globally being recycled as of 2021 (CEPİ), this challenge can be addressed successfully. The production of certain items, such as white cardboard covers, white backing boards, and various sanitary papers from recycled fibers, is both economically feasible and fulfilling.

The incorporation of chemical additives during the final stages of papermaking to enhance product quality or production efficiency is a widespread practice (Rahmaninia and Khosravani 2015). The recycling of waste paper often leads to an increase in the quantity of fines, which poses a dual concern: these fines can diminish production efficiency due to their low first-pass retention, and they can adversely affect paper properties, particularly water absorbency, in high basis weight papers. In the final stages of papermaking, various additives are frequently employed, including polyacrylamide (Jalali *et al*. 2016; Tajik *et al*. 2016) and starch (Ebrahim Berisa and Tavakoli 2015; Li *et al*. 2016), at different points in the process. Starch is traditionally added in the wet end of papermaking because of its relatively low cost and effectiveness in enhancing the mechanical properties of the paper.

It is believed that starch used in the wet end of the papermaking process is absorbed by cellulose fibers, which enhances the formation of hydrogen bonds. In contrast, polyacrylamide serves as a high molecular weight, water-soluble polymer in the paper industry, functioning as a dry strength resin and retention aid. This resin enhances retention of cellulosic fines and mineral fillers, which can improve material utilization. However, it is important to note that high dosages may lead to fiber flocculation, which can adversely affect the strength properties of the paper. Consequently, careful management of polyacrylamide dosage is essential to minimize material loss and reduce production costs.

With the advent of nanotechnology across various industrial sectors, the application of nanoparticles has become increasingly important in the paper industry, with ongoing innovations and applications. Nano-silica is among the most notable nanoparticles, and due to its size and unique surface characteristics, it is widely used as a retention aid alongside cationic materials such as cationic starch or cationic polyacrylamide. Nano-silica is recognized as an environmentally friendly additive with diverse applications in the paper and paperboard industries (Adel *et al*. 2016; Osong *et al*. 2016).

In the paper industry, the retention of fiber fines, filler retention, and water absorbency from paper pulp are crucial for determining the quality of the final product. Focusing on these three factors can enhance both the quantity and quality of paper production (Asadpour *et al*. 2015). Various strategies are employed to improve fiber bonding and strengthen the resulting products, including increased refining, the addition of virgin fibers, and the use of cationic additives aimed at enhancing the paper’s strength, optical, and physical properties (Afra *et al*. 2014).

A significant challenge facing the paper industry is the shortage of cellulosic raw materials, and this is especially acute in countries with limited forest resources. Consequently, pulp and paper industries must seek alternative sources to fulfill their cellulose requirements and alleviate the pressure on wood consumption. Currently, recycled paper fibers are being explored as an important alternative. However, a primary concern with this approach is the lower strength properties of recycled papers, which result from the fibers undergoing multiple production processes, making them weaker, shorter, and thinner than virgin fibers. Additionally, these fibers experience considerable degradation during repeated refining. The addition of fresh long fiber pulp can help mitigate some of the adverse effects associated with the shortening of recycled fibers. Nevertheless, the main challenge with this solution lies in the foreign currency needed for importing long fiber pulp, given the lack of commercial softwood forests in Iran. This research aims to compare the individual and combined effects of various additives, including nano-silica, cationic polyacrylamide, cationic starch, and long fibers, in the production of handsheet paper from recycled paper pulp.

EXPERIMENTAL

Materials

Pulp

To produce recycled white pulp, 10 kg of paper pulp was sourced from the ATRAK paper mill. Bleached softwood kraft pulp was purchased from Irkutsk Oblast Co. in Ust-Ilimsk, Russia. Before any treatment or the production of handsheets, it was refined in a PFI mill to achieve a consistency of 250 mL CSF. The resulting pulps were dewatered to a consistency of 10 to 15%, then packaged in plastic bags and stored in the refrigerator until needed.

Nano-Silica

In this study, nanosilica was made at Germany, Degussa Co. (Essen, Germany) and was used at three levels of 0, 3, and 6%. The particle diameters were 11 to 13 nm, their specific surface area was 200 m^2 per g, and their purity percentage was 99%.

Cationic Starch

The cationic starch used in this study had a pH of approximately 6, a degree of substitution (DS) of about 0.035, a protein content of less than 1%, a nitrogen content of 0.25%, and a moisture content of 10% based on wet weight. To prepare a 0.5% (w/v) starch solution (*i.e.*, 0.5 g of pure starch in 100 mL of solution), the necessary amount of impure starch was calculated, factoring in the moisture content. The determined quantity of impure starch was placed in an Erlenmeyer flask and the volume was adjusted to 100 mL using distilled water. Stirring was continuous while the temperature in the flask was monitored with a thermometer, and a foil sheet was used to cover the flask's lid to minimize water evaporation. The flask was heated gradually to 90 °C over 30 min and maintained at this temperature for an additional 30 min. Fresh starch solution was prepared daily to avoid changes in viscosity and concentration due to environmental factors.

Cationic Polyacrylamide

In this study, cationic polyacrylamide was sourced from Degussa Co. (Essen, Germany). The molecular weight was listed as 359,188 g/mol, and it had a specified average charge density. The cationic polyacrylamide was used at various concentrations. Initially, this cationic polyacrylamide was diluted with distilled water to achieve a 1% concentration based on its purity. Subsequently, 1 mL of this solution was added to a 100-mL flask containing distilled water and magnetically stirred for 3 h. The mixture was then refrigerated for 24 h. After refrigeration, the volume was adjusted to 100 mL using distilled water, and the resulting 0.1% solution was stirred again for 20 min.

Handsheet Preparation

To clarify the composition of the handsheet treatments, we emphasize that recycled white sheets were used as the main source of pulp for all formulations. The following treatments were then investigated, focusing on the effects of additional components:

Table 1. Composition of the Treatments and the Amounts of Nano-silica, Cationic Starch, and Polyacrylamide

No.	Code	Recycled White Sheets	Long Fiber Pulp	Nano-silica	Cationic Polyacrylamide	Cationic Starch
1	0LP	100	0	0	0	0
2	5LP	95	5	0	0	0
3	10LP	90	10	0	0	0
4	15LP	85	15	0	0	0
5	0.75CS	99.25	0	0	0	0.75
6	1.5CS	98.5	0	0	0	1.5
7	3NC	97	0	3	0	0
8	6NC	94	0	6	0	0
9	3NC+1.5CS	95.5	0	3	0	1.5
10	6NC+1.5CS	92.5	0	6	0	1.5
11	0.07CPAM	99.93	0	0	0.07	0
12	0.15CPAM	99.85	0	0	0.15	0
13	3NC +0.15CPAM	96.85	0	3	0.15	0
14	6NC +0.15CPAM	93.85	0	6	0.15	0

Consequently, 14 treatments with various formulations were developed, each comprising 10 sample replicates. The handsheet paper was produced following the standard procedure TAPPI T205 sp-02 (2002), utilizing a manual papermaking machine. The target basis weight for the paper in this study was set at 127 g/m².

Measurement of Paper Properties

The physical and mechanical properties of the handsheet paper were assessed following TAPPI standards, as detailed in Table 2. The basis weight of the paper was determined using a laboratory balance with an accuracy of 0.01 g, while the paper thickness was measured with a caliper. The mechanical properties of the paper sheets, including tensile index, and tear strength, were measured using a Lorentzen & Wettre (L&W, Kista, Sweden) tensile strength tester for tensile testing and an Elmendorf tearing tester (ZB-SL Hangzhou, China) for evaluating tear strength. The air permeability (using the Gurley method) and surface smoothness (assessed by the Bekk method) of the papers was determined with a Lorentzen & Wettre (L&W, Kista, Sweden) Air Permeance tester. Also, the paper apparent density was measured at different treatments with relation between caliper and basis weight of papers

Table 2. Properties of the Tested Handsheets Papers

Properties	Standard No.
Water absorption (g/m²) Cobb test	TAPPI T441 om-96 (1996)
Surface smoothness (s)	TAPPI T479 cm-21 (2021)
Air resistance (s) Gurley permeability	TAPPI T460 om-06 (2006)
Tensile index (N.mg^{-1})	TAPPI T494 om-06 (2006)
Burst index (kPam^2.g^{-1})	TAPPI T403 om-15 (2015)
Tear index (mNm^2.g^{-1})	TAPPI T414 om-12 (2012)

Microscopic Studies

The surfaces of the handsheet paper were analyzed using a field-emission scanning electron microscope (FE-SEM) model MIRA3 TESCAN-XMU, manufactured in the

Czechia and hosted at the Razi Metallurgy Research Institute. The experimental design employed in this study was completely randomized. For data analysis, one-way analysis of variance (ANOVA) and *post-hoc* group mean comparisons using Duncan's test at a 95% confidence level were conducted with SPSS software (IBM Software, version 23, Armonk, NY, USA).

RESULTS AND DISCUSSION

The significance level of differences among the studied properties of the handsheet paper is presented in the analysis of variance table (Table 3). The impact of additives on apparent density, water absorption, surface smoothness, air permeability, tensile index, tear index, was statistically significant at a 95% confidence level. The study was conducted experimentally on handmade papers. However, the obtained results can significantly be generalized to machine-made papers. In particular, the effect of additives such as CPAM and nano-silica on the surface smoothness of paper and print quality is observable in both types of paper. Since there was no return of fines-rich process water in the production of handsheets, the results may appear somewhat exaggerated compared to machine-made papers. Therefore, for further validation, it is recommended that experiments be conducted on machine-made papers to examine similar effects.

Table 3. Analysis of Variance (F Value and Significance Level) of the Effect of Treatments on the Properties of Handsheets

Properties	F
Water absorption (g/m^2)	4400.59*
Surface smoothness (s)	2.94*
Air resistance (s)	16.72*
Tensile index (N.mg^{-1})	64.54*
Burst index (kPam^2.g^{-1})	97.79*
Tear index (mNm^2.g^{-1})	18.97*

*Significant at the 95% confidence level; ns not significant at the 95% confidence level

Apparent Density

The apparent density of paper significantly influences many of its properties (Asta *et al*. 2024). It is a critical physical characteristic used to assess the paper's structure and compactness, and it plays a vital role in optimal heat transfer during the drying process (Pourkarim Dodangeh and Jalali Torshizi 2018). Higher apparent density often correlates with increased mechanical strength, which can also impact air resistance due to a more compact structure that reduces voids for air passage. In packaging papers, increased apparent density can enhance flexural stiffness but may also lead to tearing during the wetting phase of the corrugation process (Niskanen 1998). However, it is important to note that apparent density is a physical property and does not directly indicate strength. Generally, bulky paper, which contains more air, may not be as compact or strong as less bulky paper. Strength is more closely related to the quality of fiber-to-fiber bonding and the overall fiber structure (Main *et al.* 2015).

As shown in Table 3, there was a significant difference in the average apparent density among the papers produced from the 14 pulp combinations (Fig. 1). The apparent density values of the handsheet papers ranged from 1.5 to 1.79 g/cm^3, with the addition of 15% long fibers yielding the highest apparent density. However, the incorporation of long fiber pulp, due to the rough nature of these fibers, tends to increase the apparent bulkiness while affecting the overall density, classified in statistical group "m" according to Duncan's grouping. Furthermore, the independent use of nano-silica resulted in a reduction in apparent density compared to the control sample. This reduction may be attributed to the limited retention of nano-silica in the absence of a cationic polymer.

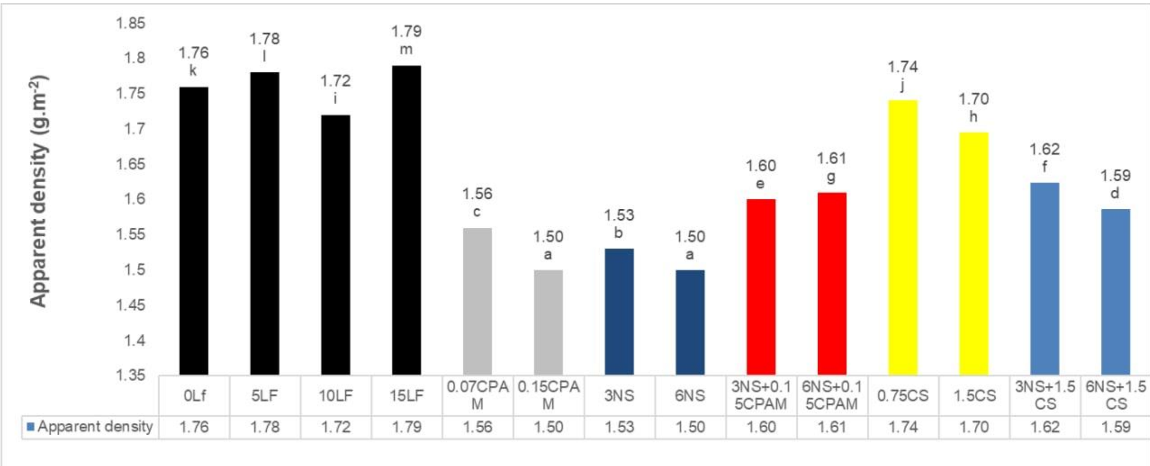


Fig. 1. Comparison of apparent density of pulp and paper and grouping of averages

Effect of Additive Variables on Water Absorption

As indicated in Table 3, there was a significant difference in the average water absorption among the papers produced from the 14 pulp combinations, with Duncan's grouping categorizing the means into 11 distinct groups (Fig. 2). Water absorption capacity was closely linked to the paper's density, as denser papers typically exhibit lower porosity and, consequently, reduced water absorption. The highest water absorption was noted in the papers that contain 5% long fibers independently, while the lowest water absorption, measuring 119 g/m², was observed in the papers with 3% nano-silica and 0.15% cationic polyacrylamide.

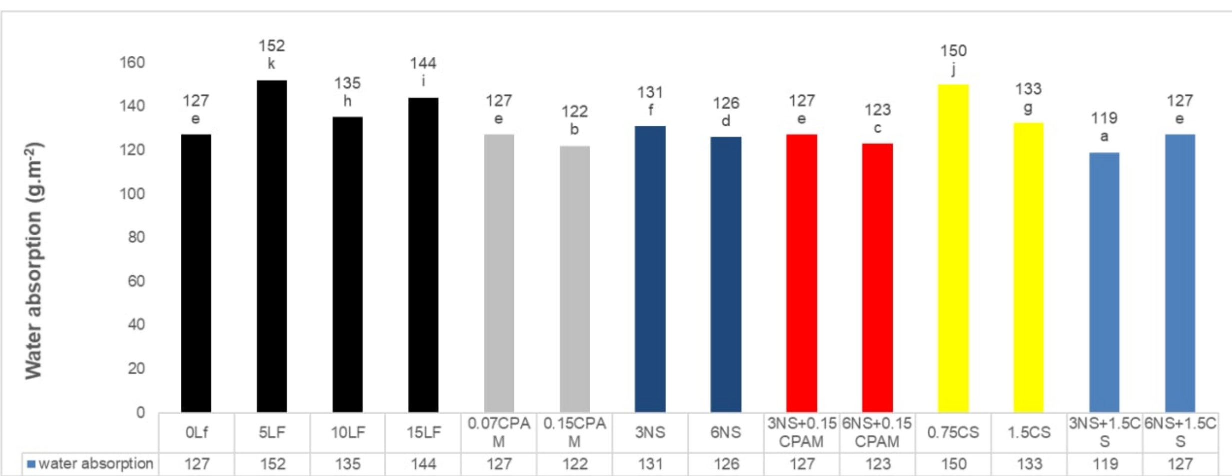


Fig. 2. Comparison of water absorption of pulp and paper and grouping of averages

Effect of Additive Variables on Surface Smoothness

Surface smoothness is a crucial structural characteristic of paper that is particularly important for enhancing printability and achieving higher print quality (Aydemir *et al.* 2021). There is an expected relationship between surface smoothness and air resistance; smoother surfaces typically exhibit lower air resistance due to fewer surface irregularities that can obstruct airflow. The lowest surface smoothness, measuring 4.93 s, was associated with 0.07% cationic polyacrylamide (Group a – Fig. 3). This result may be attributed to the insufficient interaction of CPAM at this lower concentration, which may not effectively enhance fines retention or fill the voids between fibers. In contrast, the highest smoothness, recorded at 7.1 s, was found in the combined treatments containing 3% nano-silica and 1.5% cationic starch (Group b – Fig. 3). Surface smoothness is heavily influenced by the average length of cellulose fibers, the presence of cellulose fines, and their retention within the paper network, which collectively determine the quality of paper formation. Consequently, it reflects the effectiveness of additives in a specific pulp suspension. For instance, the aggregation of nano-silica particles can enhance the surface smoothness of paper (Hamzeh and Rostampour-Haftkhani 2008). Improved retention of fines, facilitated by effective binding agents that fill the gaps between fibers, leads to increased surface smoothness, thereby enhancing print quality. The combination of cationic starch and cationic polyacrylamide has also resulted in improved surface smoothness, likely due to the uniform distribution of these additives across the surface.

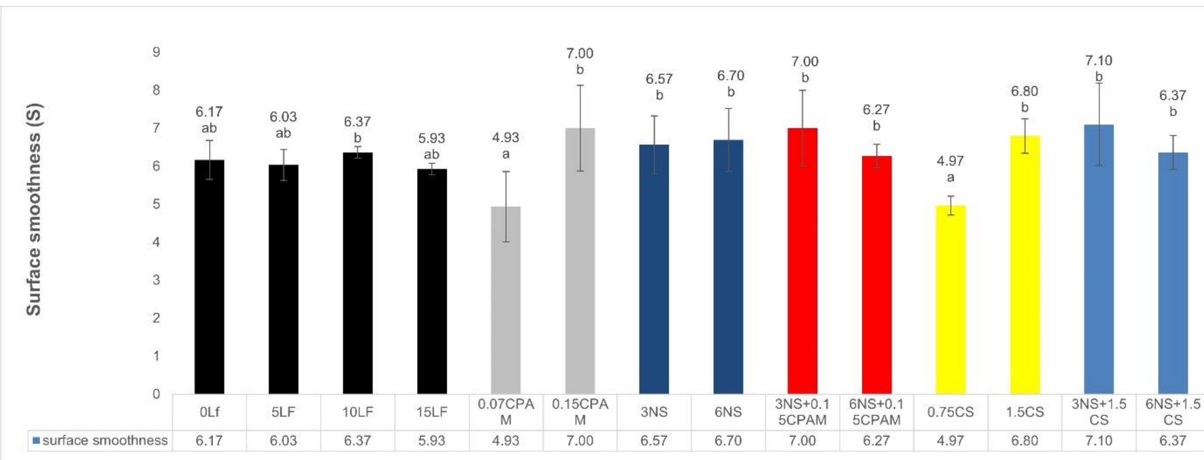


Fig. 3. Comparison of surface smoothness of pulp and paper and grouping of averages

Effect of Additive Variables on Gurley Air Resistance

Figure 4 displays the average variations in air permeability across the 14 types of handsheet papers. Air resistance is influenced by apparent density, as denser papers with improved fiber bonding tend to allow less air passage due to their compact structure, resulting in higher resistance values. Typically, as the uniformity of paper formation improves, its air resistance increases, reflecting better fiber distribution and bonding. The average air resistance values have been classified into six distinct groups according to Duncan's grouping. Air resistance serves as an indirect indicator of the paper's internal structure, which is influenced by the distribution of additives, fibers, fines, and the overall quality of paper formation (Asadpour *et al.* 2015). For instance, studies have shown that improved paper formation reduces defects but can also lead to increased permeability under certain conditions (Rasi 2013). The average resistance values in all treatments were higher compared to the control. Notably, the value associated with 0.07% polyacrylamide was the lowest among the treatments at 2.98 s, indicating a decrease in air resistance. This reduction can be linked to fewer paper defects, leading to higher air permeability. However, an excessive increase in air permeability can impede the operation of paper pick-up sections in the printing machine feeder.

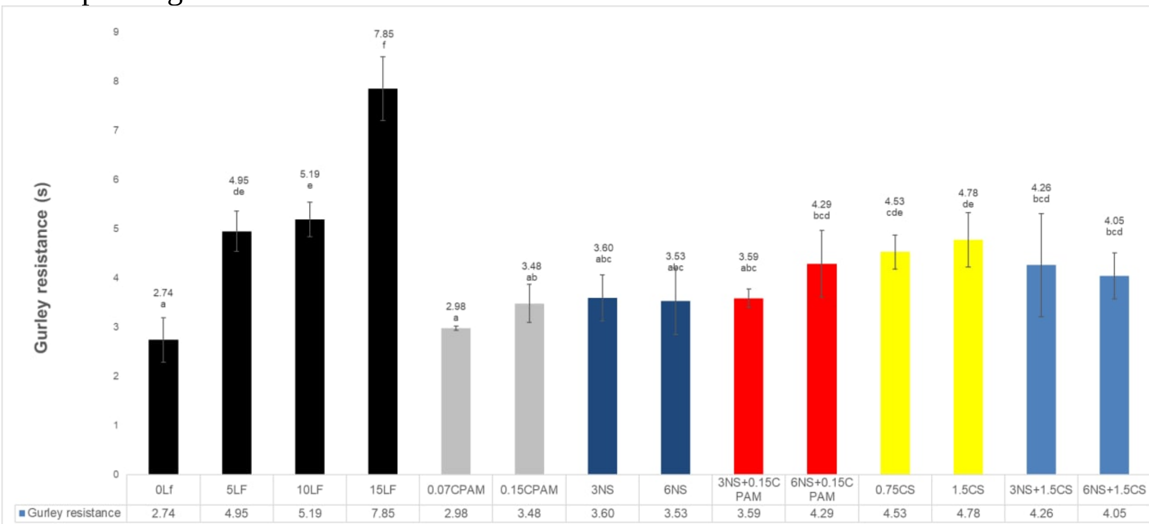


Fig. 4. Comparison of Gurley resistance of pulp and paper and grouping of averages

Effect of Additive Variables on the Tensile Index of Handsheet Paper

The tensile strength of paper is primarily influenced by three main factors: 1) the intrinsic strength of the fibers; 2) the bonding strength between the fibers, and 3) the flexibility of the fibers. Tensile strength also has a direct correlation with apparent density; papers with higher density often exhibit enhanced tensile strength due to better fiber-to-fiber bonding and a more uniform structure. This strength is one of the most critical practical characteristics of various types of paper and paperboard, influenced by fiber strength, the quantity and quality of fiber-to-fiber bonds, and the overall paper formation (Borodulina *et al.* 2018). The type and amount of additives used in papermaking affect the distribution of fiber components, which in turn impacts paper formation and the number and strength of the bonds. These additives also influence fiber flocculation, water absorption, and bonding (Lee *et al.* 2011). Generally, the addition of cationic starch enhances tensile strength while reducing tearing of the paper. However, the effectiveness of this additive depends significantly on its quantity and the type of pulp used (Pathak *et al.* 2011). The use of cationic starch alone increased the tensile strength compared to the control sample, placing its average value in independent group h according to Duncan's grouping. The highest tensile strength, recorded at 41.9 Nm/g, was associated with 15% long fibers, categorized in group f. Long fibers, particularly when refined, contribute to this strength due to their high intrinsic tensile properties. Conversely, the use of nano-silica alone resulted in a decrease in tensile strength, as the absence of a cationic polymer means no expected benefits from the colloidal silica. In this context, the conditions with nano-silica can be regarded as a "control." Given the absence of a deinking system at ATRAK paper mill and the presence of ink particles in the pulp, it is likely that the bonding and deposition of nanoparticles with the base pulp fibers were suboptimal (Lee *et al.* 2011). This limitation underscores the importance of effective deinking processes in enhancing paper quality. Previous studies have reported increases in the tensile index of waste office paper and photocopy paper following the deinking of their pulp (Lee *et al.* 2011; Pathak *et al.* 2011).

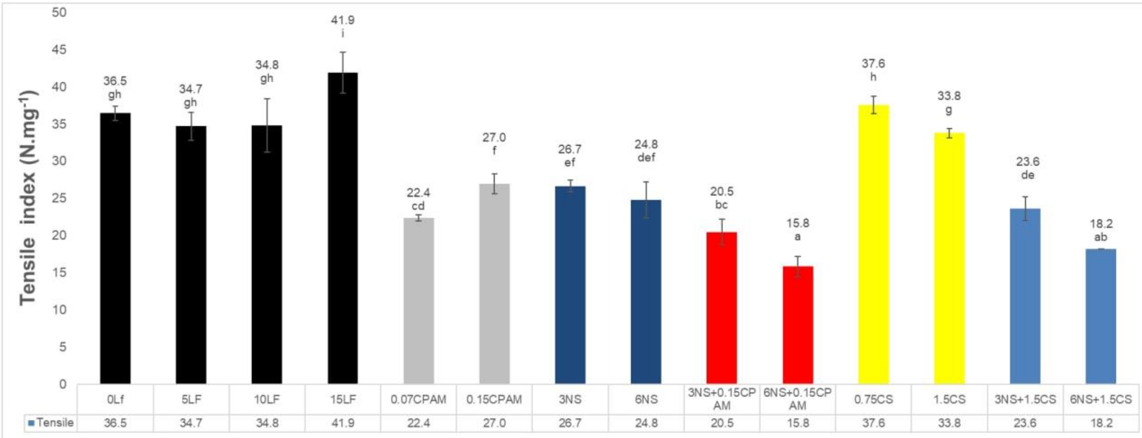


Fig. 5. Comparison of pulp and paper tensile index and grouping of averages

Effect of Additive Variables on the Burst Index of Handsheet Paper

Burst strength is a property that primarily depends on fiber length and the bonding levels between fibers, with a significant influence from fiber-to-fiber bonding (Kiaei *et al.* 2016). Figure 6 illustrates the average variations in the burst index for the 14 types of handsheet papers.

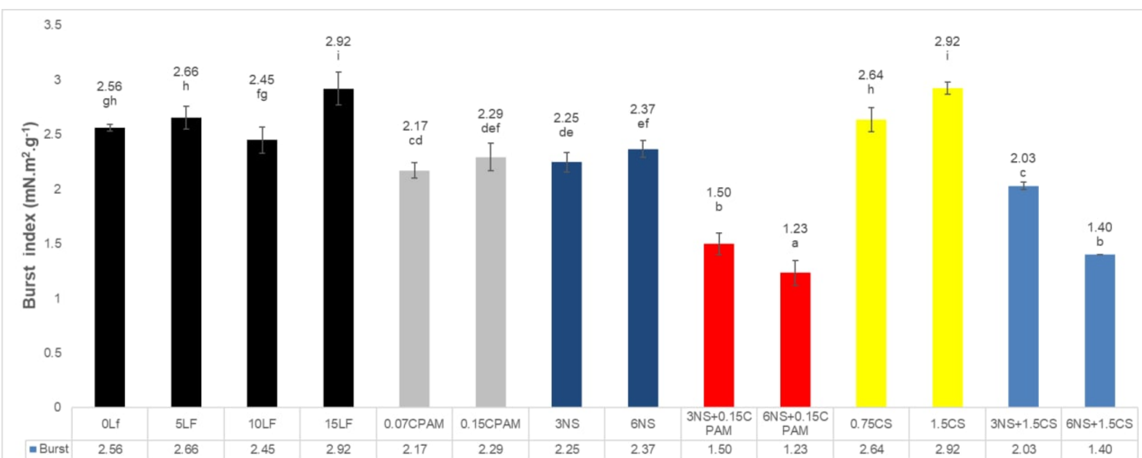


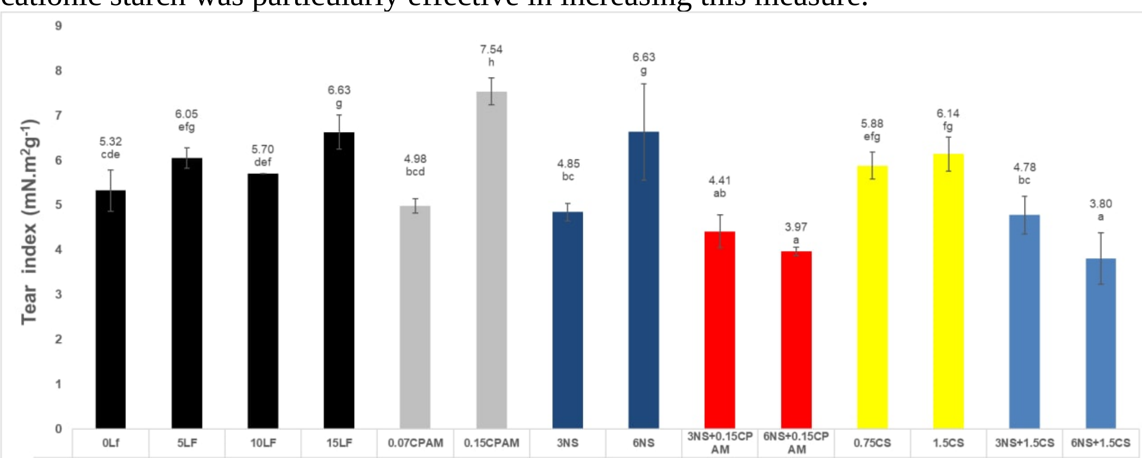
Fig. 6. Comparison of pulp and paper burst index and grouping of averages

Duncan's grouping categorized the average values of the burst index into nine distinct groups. Like tensile strength, burst strength can also be affected by apparent density, as denser papers typically display improved burst resistance due to enhanced structural integrity. The addition of cationic starch resulted in the most significant increase in this index compared to the control sample. Rezayati Charani *et al.* (2018) also noted the effects of adding 1% cationic starch and 3% nano-silica in binary sequences. Initially incorporating a cationic binder enhances bridging between the fibers, and with the subsequent addition of nano-silica, anionic nanoparticles integrate into the binder-fiber network. If anionic nanoparticles are added first, they occupy the cationic sites on the binder chains when the cationic binder is introduced, leading to reduced bridging between fibers (Latibari *et al.* 2011). Therefore, starting with the cationic binder is presumed to enhance the burst index of the paper. Because starch exhibits good compatibility and a high affinity for the anionic surfaces of cellulose fibers, it facilitates the formation of electrostatic and hydrogen bonds (Pourkarim Dodangeh *et al.* 2021). The strong compatibility and high affinity of cationic starch with cellulose fibers significantly promote the establishment of these bonds, having a more pronounced effect than the addition of 10% long fibers.

Effect of Additive Variables on the Tear Index of Handsheet Paper

This characteristic is a key qualitative evaluation parameter for paper and cardboard, particularly in packaging applications. The tear index is influenced by both the density and bonding quality of the paper; higher density often indicates improved fiber bonding, which can lead to increased brittleness and lower tear resistance. The main factors influencing paper strength include the average length and diameter of the fibers, as well as the inherent strength of the fibers used in production. Additionally, the bonding between components and the orientation of fibers within the paper structure also play significant roles (Ek *et al.* 2009). In terms of tear strength, the length and strength of the fibers are the most impactful factors. However, if these two factors are held constant, the quality of fiber-to-fiber bonding positively affects tear strength, as higher bonding levels may result in decreased tearing energy consumption (Ebrahim Berisa and Tavakoli 2015).

Figure 7 displays the average variations in this indicator for 14 types of handsheet paper, categorized into eight independent groups according to Duncan's classification. In all treatments, except for both the independent and combined use of cationic polyacrylamide, the tear index of the handsheet paper was greater than that of the control treatment. The presence of fine ink particles and anionic substances in the white pitch may negatively affect tear strength. The highest tear strength, found in group H, is associated with the addition of 0.15% polyacrylamide. The incorporation of cationic starch in combination also enhances tear strength, likely due to the restoration of lost bonding points on the surface of recycled fibers. Cationic starch improves fiber-to-fiber bonding, thereby enhancing this indicator (Heermann *et al.* 2006). The independent addition of 0.75% cationic starch was particularly effective in increasing this measure.



	0Lf	5LF	10LF	15LF	0.07CPAM	0.15CPAM	3NS	6NS	3NS+0.15CPAM	6NS+0.15CPAM	0.75CS	1.5CS	3NS+1.5CS	6NS+1.5CS
Tear	5.32	6.05	5.70	6.63	4.98	7.54	4.85	6.63	4.41	3.97	5.88	6.14	4.78	3.80

Fig. 7. Comparison of pulp and paper tear index and grouping of averages

Microscopic Studies of Paper Structure (FE-SEM)

The micrographs in Fig. 8 illustrate the structure of handsheet papers produced from recycled white pulp: without additives (a), with the addition of 15% long fibers (b), with 6% nano-silica and 1.5% cationic starch (c), and with 6% nano-silica and 0.15% cationic polyacrylamide (d). The addition of nano-silica, in combination with either cationic starch or cationic polyacrylamide, appears to have minimized defects in the papers.

The incorporation of nanoscale particles can enhance the overall structural integrity of the paper by improving bonding and distribution among fibers. However, the results indicated that the water absorption capacity values for the control (123 g/m²), 6% nanosilica + 1.5% starch (127 g/m²), and 6% nanosilica + 0.15% CPAM (123 g/m²) did not show significant differences. While the addition of nanosilica did reduce bulk, it did not have a substantial effect on water absorption capacity in these formulations (Lagaron *et al.* 2004; Rezayati Charani *et al.* 2018). This reduction in water absorption capacity can impact the efficiency of the paper machine, as it may affect the drying process and overall production rates. While water absorption capacity is primarily a property of the final paper product influenced by its structure and hydrophilicity, the ability of the paper to retain moisture during processing can play a role in machine performance.

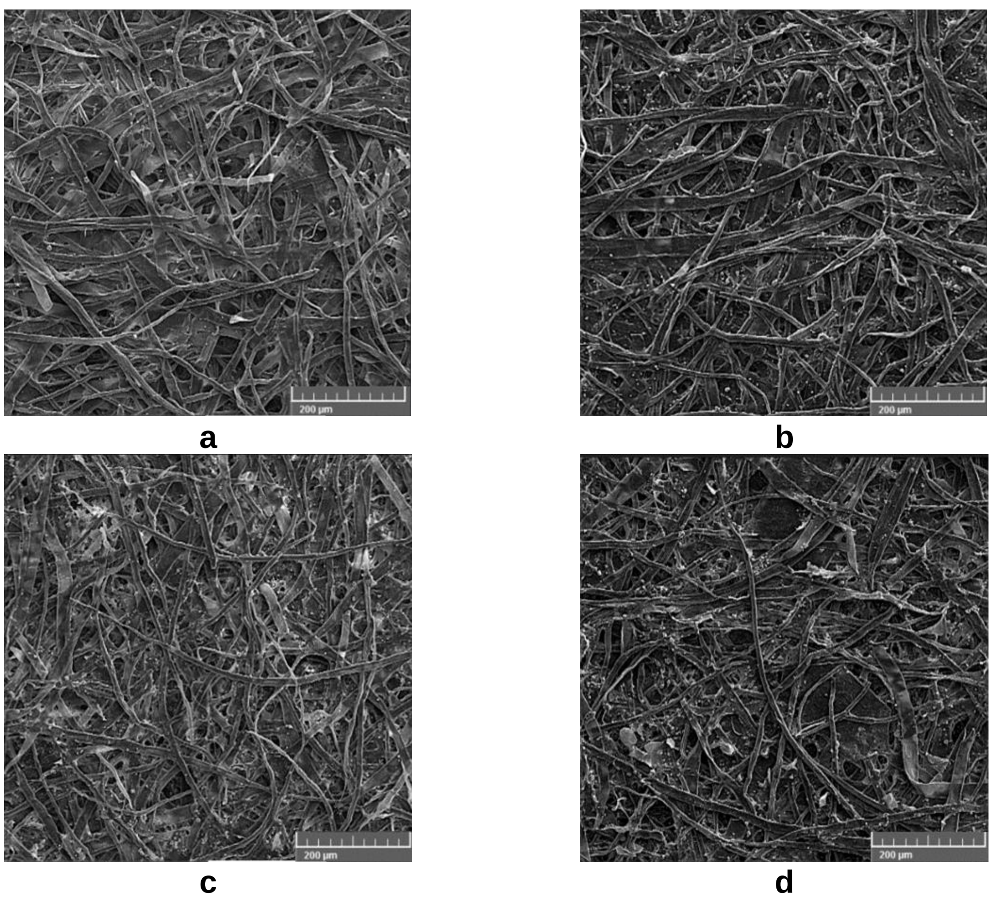


Fig. 8. The surface of papers produced from paper pulp: (a) 0% long fibers, (b) 15% long fibers, (c) 6% nano-silica and 1.5% cationic starch, (d) 6% nano-silica and 0.15% cationic polyacrylamide

CONCLUSIONS

This study has highlighted significant effects of various additives on the properties of handsheet papers made from recycled white pulp. The results indicate that both independent and combined use of these additives can lead to diverse impacts on the physical characteristics of the paper. Notably, the combination of cationic polyacrylamide improved surface smoothness and enhanced printability. The addition of long fibers increased tensile and tear strength while also leading to higher air resistance, which can be beneficial for handling sheets with a vacuum pick-up device. The highest tensile and tear strength values were achieved with the addition of 15% long fiber pulp.

Microscopic analyses revealed that specific additives reduced structural defects in the paper, which could improve machine efficiency. In conclusion, this research emphasizes the importance of additive selection and formulation in optimizing handsheet paper properties, The order of addition—starting with nanosilica, followed by cationic starch, and finally cationic polyacrylamide—plays a crucial role in achieving the desired effects. Future studies should focus on developing improved deinking technologies to enhance the quality and performance of recycled papers. The results are summarized:

1. The independent and combined use of additives can produce varying effects on the properties of paper pulp derived from recycled white pulp.
2. The highest surface smoothness was found in treatments that combined nanosilica and polyacrylamide, enhancing the printability of the paper surface and reducing the need for sizing.
3. However, the addition of long fibers increased air resistance and decreased water absorption, potentially causing challenges in printing and paper machine operations.
4. The greatest tensile strength and tear strength in handsheet papers were achieved with the addition of 15% long fiber pulp. Additionally, the independent use of 0.75% and 1.5% cationic starch also improved these properties compared to other treatments.
5. The utilization of long fiber pulp and cationic starch independently offers various benefits and adds value in enhancing the properties of recycled papers made from recycled white pulp.
6. Given that the recycled white pulp from the ATRAK factory consistently contains ink particles due to the absence of an ink removal system, the lack of a positive effect of cationic polyacrylamide on the properties of handsheet papers can be attributed to this factor.
7. Micrographs of the paper structure from different treatments, in comparison to the control sample, showed a reduction in paper defects with the addition of specific additives, which could positively influence the operational speed of the paper machine.

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