Surface Treatment of Laboratory-made Papers: Impact on Water Absorption and Structural Characteristics

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This study investigated how coatings with sodium polyacrylate (SP), mixed corn starch (MS), and their combination (SPMS) affect the properties of lab-made cellulose papers. Coatings were applied at various dry matter concentrations (5 to 20% w/w). Results showed that SP coatings significantly increased water retention and hydrophilicity, with higher concentrations improving absorption. Conversely, MS coatings reduced water retention. Gloss values slightly increased with coating concentration but were overall lower than the uncoated paper. Structural properties like density and thickness were largely unchanged, confirming the coating's direct impact on grammage and water absorption. This preliminary laboratory study provides a foundational framework for optimizing coating color formulations and their application to paper surfaces, offering insights for developing next-generation paper products for various industrial and commercial applications.

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INTRODUCTION

This experimental study aimed to investigate the effect of the content and concentration of coating colors on the absorbency of paper material surfaces. In this study, corn starch mixed with sodium polyacrylate and polyvinyl alcohol, which are often used as components in superabsorbent polymers, was applied to the paper surface at different concentrations as a coating color. In addition, the substrate papers on which the coating colors were applied as a surface treatment were produced in a laboratory environment from cellulose fibers as laboratory-made papers without the use of any paper chemicals. Thus, the properties of the paper and the effects of the coating on paper absorbency were investigated by ignoring the interaction between the coating color applied as a surface treatment and the commercial paper chemicals used in other pulp components. In addition, the synergistic effect of sodium polyacrylate and mixed starch as coating colors was investigated. The results of this study also may serve as a basis for determining the optimum concentration at which the coating color should be prepared to give the paper the desired absorbency and prevent leakage problems.

Absorbent papers are classified as specialty papers (Dutt 2013). Absorbent specialty papers are products consisting of fibers with high water and oil absorbencies and porous surfaces. The water absorbency of paper is affected by the capillary spaces within and between the fibers in the paper, the mechanical and chemical pulp production variables to which the fibers are exposed, and the degree of collapse of the fibers in the paper web during the pressing of the paper (Dutt *et al.* 2003).

Liquid absorbency, maximum unbound fiber surface area, surface voids, pores, bulkiness, and wet resistance strength are among the product-specific qualities characteristic of an absorbent paper material (Dutt *et al.* 2003). Paper-based materials can be treated with various chemicals to enhance their absorbent properties. Sodium polyacrylate is a chemical compound used in absorbent diapers and feminine hygiene pads (Castrillon *et al.* 2019).

In the field of baby care products, sodium polyacrylate is used to absorb water molecules in urine and increase the liquid retention capacity of diapers (Bachra *et al.* 2020; Zhang *et al.* 2021). In addition, the use of sodium polyacrylate in diaper production promotes a dry environment, reducing the risk of diaper rash (Ma *et al.* 2018). Sodium polyacrylate is commonly referred to as a water lock; it is a sodium salt of polyacrylic acid with the chemical formula $[-CH_2-CH-]_n$. It has a variety of consumer product applications and is a superabsorbent polymer that can absorb up to 1000 times its mass in water (Geesing and Schmidhalter 2004; Ma *et al.* 2018). It is widely used thickening agent because of its exceptional ability to absorb and retain water molecules. Being hydrophilic in nature, sodium polyacrylate polymer structurally contains sodium (Na+) and carboxylate (COO-) ions. When this polymer interacts with any aqueous solution, the positively and negatively charged ions in its neutral state interact with the solution, and Na+ ions dissolve in the aqueous solution and separate from the polymer chain (Wang *et al.* 2011). The superabsorbent hydrogel, formed from cross-linked sodium polyacrylate, functions through ionic repulsion and osmotic pressure. When hydrated, the sodium ions (Na^+) dissociate from the polymer backbone, leaving behind negatively charged carboxylate groups (COO^-) along the chains. These like-charged sites repel each other electrostatically, causing the polymer network to expand. However, the covalent cross-links between the chains prevent dissolution, creating a three-dimensional gel structure. This expanded network, combined with the osmotic pressure generated by the concentrated counterions (Na^+) trapped within, enables the hydrogel to absorb and retain from 100 to 1,000 times its dry weight in water (Gupta and Natarajan 2019; Behera and Mahanwar 2020). This makes it an ideal ingredient for hair gels and diapers. It is also used in industrial processes to dissolve soap by absorbing water molecules. Thickening agents, such as sodium polyacrylate, increase the viscosity of water-based substances, thereby improving their stability. The superabsorbent hydrogel based on cross-linked sodium polyacrylate finds application in agriculture, where it is incorporated into potting soils to improve water-holding capacity to help them retain moisture by acting as a water reservoir (Geesing and Schmidhalter 2004).

In the industry, starch is used to improve the surface of paper materials, especially in surface glueing, pigment-containing coating processes, and functional coating processes because of its fully biodegradable nature, widespread availability, and low cost (Li *et al.* 2019; Nowak *et al.* 2022). In general, the use of starch as a surface coating agent is limited because of its poor mechanical properties, low thermal stability, high moisture sensitivity, and susceptibility to damp mold (Mohanty *et al.* 2018; Wu *et al.* 2023). To overcome these negative qualities, organic or inorganic fillers and functional chemicals can be added to starch structures. The mechanical and barrier properties of the mixed starch can be improved.

In this study, to create a controlled and well-defined substrate for coating, laboratory handsheets were first produced from pure cellulose pulp without any fillers or chemical additives. The objective was to enhance the liquid absorbency of the pure cellulose papers through surface coating. This was achieved by applying laboratory-prepared coating colors containing sodium polyacrylate at different concentrations. The coated papers exhibited increased swelling and absorption without structural disintegration, aligning with findings from prior work (Zhang *et al.* 2021). In addition, specific to this study, sodium polyacrylate was mixed with polyvinyl alcohol, and starch was used separately and together with polyvinyl alcohol to form coating colors with different contents and concentrations, which were applied to the paper surface, inspired by related studies in the literature (Zhu *et al.* 2018; Huang *et al.* 2022; Tarnowiecka-Kuca *et al.* 2023). Thus, the optimum coating color content that should be prepared and applied to be transformed into a new product with high added value was investigated, and the relationship of the prepared coating colors with pure cellulose fibers was analyzed.

As a novel feature of the present work, it is hypothesized that paper products having valuable sets of properties can be achieved by coating the base paper with components of superabsorbent polymer systems, but without the use of a crosslinking agent. This approach fundamentally differs from conventional superabsorbent polymer coatings, which typically rely on crosslinking agents to achieve water retention and gel strength. A motivation is to avoid the cost and effort associated with the usage of various crosslinking agents. Future research can address possible adverse consequences, as well as additional options related to leaving out crosslinking agents from highly water-absorbing coatings for paper.

The most important reason for choosing wood fiber-based paper material in this study is that paper-based materials are lightweight, recyclable, environmentally friendly, cheap to produce, have good mechanical properties and can be easily preferred for different needs (Reddy 2015; Youssef and El-Sayed 2018). Previous studies have also shown that the anti-leakage barrier properties of paper are improved by coating processes applied to the paper surface (Kjellgren *et al.* 2006; Hu *et al.* 2009; Kopacic *et al.* 2018). Through applying various chemicals to cellulose-based materials, they can be transformed into products, such as superabsorbents, water retention capacity-enhanced baby diapers, feminine hygiene products, adult patient diapers, and laboratory papers for special applications (Hubbe *et al.* 2013; Simões *et al.* 2025). In this laboratory-scale study, the prototype of a product with the potential to serve many different fields by imparting absorbency and anti-leakage barrier properties to paper consisting of pure cellulosic fibers was tested with laboratory-scale production without using commercial paper chemicals with minimum additives.

EXPERIMENTAL

Materials

In this study, birch fibers were used for papermaking. Sodium polyacrylate, carboxymethyl cellulose (CMC), polyvinyl alcohol, and starch are commercially available raw materials and were purchased ready to use.

The raw materials used in this study, along with their key specifications, are listed in Table 1. Laboratory-made papers were formed from bleached birch kraft pulp. The coating formulations were prepared using commercial products of sodium polyacrylate, carboxymethyl cellulose (CMC), polyvinyl alcohol (PVA), and starch, all of which were used as described as the following sections.

Table 1. Raw Materials Used in the Study

Material	Supplier	Product Code	Key Specifications
Cellulose	METSA	HSN Code 470329	Birch kraft pulp, 14 Schopper-Riegler (°SR) value
Sodium polyacrylate	Ataman Kimya	Acumer 1100	Molecular weight 94.04 g/mol
Carboxymethyl cellulose	Labor	9004-32-4	99.5% purity
Polyvinyl alcohol	Blab	PVA 1788	Molecular weight 89000 - 98000 g/mol
Starch	Hammaddeler	TR-35-K-047442	Corn starch

Pulp Preparation and Its Application in Laboratory-made Papers

To fibrillate the fibers that make up the pulp content and form stronger bonds, cellulose fibers were exposed to mechanical impact in the laboratory Hollander-type beating device, and wet pulp beating was completed in accordance with the ISO 5264-1 (1979) standard method. For this purpose, commercial birch fibers were prepared for beating by soaking in 5 L of distilled pure water for at least 4 h. To use only long fibers in papermaking, fibers called very short crumb fibers were removed using a laboratory-type fractionator device with an 80-mesh sieve opening according to the TAPPI T275 sp-23 (2023) standard method. The drainage resistance of the pulp was characterized using a Schopper-Riegler apparatus according to ISO 5267-1 (1999). The water-holding capacity of the wet pulp sample was measured and calculated with reference to the TAPPI UM 256 (2011) standard methods.

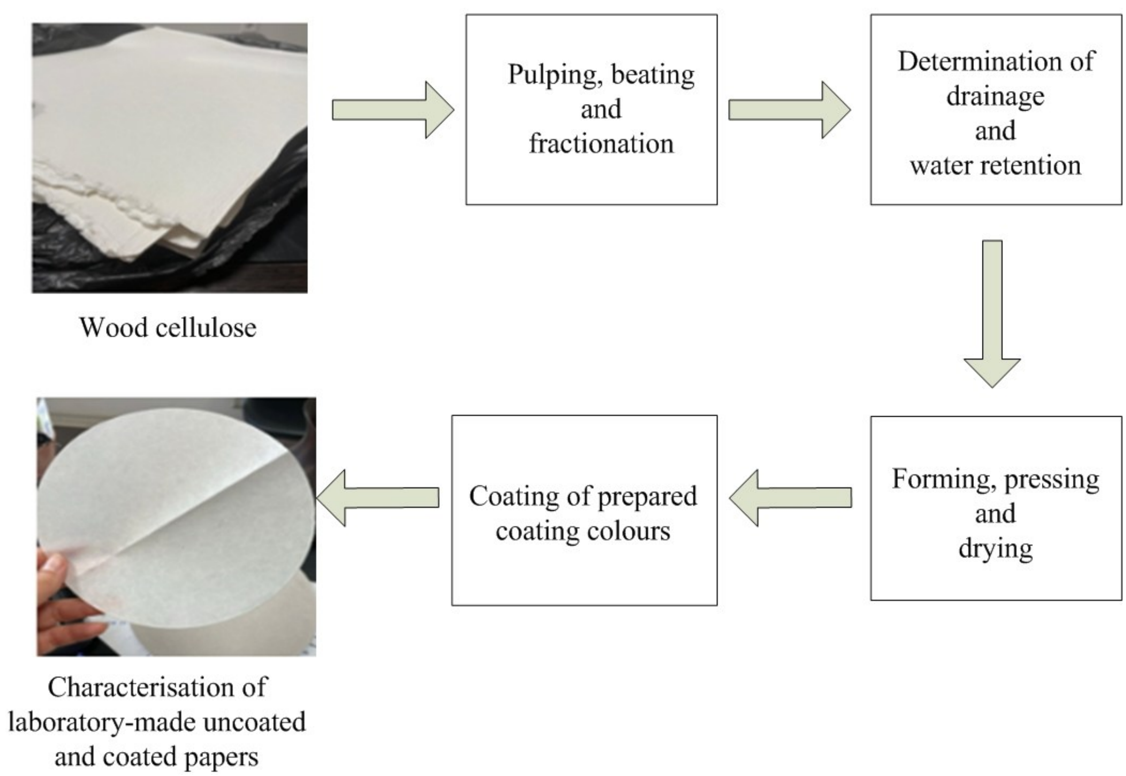

Fig. 1. Stages of production and coating of laboratory-made base (control) papers with coating color

The basic principles of ISO 5269-1 (2005) were applied in paper production. The paper weight was determined to be 60 g/m^2. The pulping, laboratory-made paper production, and coating processes are illustrated in Fig. 1 as a step-by-step flow diagram. A laboratory-type standard Handsheet Sheet Former device was used for paper formation. To remove the water in the structure of the formed paper sheets, the pressing process was completed using a hydraulic press by applying 345 kPa press pressure specified in the standard method (ISO 5269-1 2005). The pressed papers were dried naturally at room temperature, and circular drying discs, metal plates, and weights placed on the discs were used to prevent any wrinkles or damage on the surfaces of the papers.

The physical, structural, and water absorption properties of the laboratory-made papers were determined before surface treatment, and these papers were used as control samples. The produced papers were conditioned at 50 ± 2% relative humidity and 23 ± 1 °C for 24 h and prepared for physical tests in accordance with the ISO 187 (2022) standard.

In this study, different concentrations of sodium polyacrylate coating colors were prepared to measure the activity of sodium polyacrylate as a coating color. In addition, the coating color recipe was diversified using mixed starch. While preparing the coating color, distilled water was used as the solvent, and a constant amount of CMC was used as the binder. During the preliminary trial coating color preparation, values ranging from 10 to 30% were planned for the concentration of sodium polyacrylate, but after the coating color preparation, difficulties were experienced in the application and homogeneous distribution on paper due to the rapid absorption of water by sodium polyacrylate. Therefore, the concentrations of sodium polyacrylate and starch components in the coating color were changed between 2.5 and 20 ‰ and 2.5 and 20 %, respectively. For each coating formulation, polyvinyl alcohol was incorporated at a concentration of 1% (w/w) relative to the total mass of the solution. The content of the prepared coating colors is summarized in Table 2.

Table 2. Coating Color Contents and Paper Sample Codes *

Number of Coating Colors	Specimen Code	Sodium Polyacrylate (‰)	Mixed Starch (%)	Binding Agent (CMC) (%)
1	SP5	5	0	2
2	SP10	10	0	2
3	SP15	15	0	2
4	SP20	20	0	2
5	SPMS5	2.5	2.5	2
6	SPMS10	5	5	2
7	SPMS15	7.5	7.5	2
8	SPMS20	10	10	2
9	MS5	0	5	2
10	MS10	0	10	2
11	MS15	0	15	2
12	MS20	0	20	2

*All formulations contained polyvinyl alcohol as a 1% (w/w) additive relative to the total coating color weight.

The coating colors prepared according to Table 1 were applied to the surface of the produced papers using a cylindrical glass rod. Coating colours with wet weights of 12 g/m² and dry matter concentrations of approximately 5%, 10%, 15%, and 20% (w/w) were applied to each of lab-made papers using a rolling glass rod. During application, care was taken to use the rod with constant speed and pressure to ensure a homogeneous distribution of the coating color on both surfaces of the paper. After the surface coating process, the treated paper samples were left to dry naturally for 24 h under normal room conditions. After one side of the paper sample was coated with the coating colors and dried, the other side was also coated so that both sides were treated with the sodium polyacrylate coating color. Wooden weights were placed at the edges of the samples to prevent curling during drying. The paper samples to be coated with different concentrations of sodium polyacrylate were referred to by sample codes, as shown in Table 1. The laboratory-made uncoated paper that is not listed in Table 1 was designated as the control sample (C).

Determination of Physical and Structural Properties of Laboratory-made Papers

It should be noted that the use of the circular shape laboratory-made papers, instead of the rectangular ones, for glass rod coating may introduce minor heterogeneity in coating application at the edges; however, all tested properties were measured on the central area of the laboratory-made papers where visual inspection confirmed uniform coverage.

The ISO 536 (2019) standard method was used to determine the weight of the paper. Grammage was measured using sensitive electronic scales and expressed in g/m² units. The average thickness values of the papers were determined according to the ISO 534 (2011) standard method by measuring the distance between the top and bottom surfaces of the paper in micrometers. With the help of a special purpose micrometer, measurements were taken from 10 different points of 10 layers of paper and the thickness values were expressed in µm by averaging these values.

The ISO 534 (2011) standard method was used to determine the density of the laboratory-made papers. The density value was calculated according to Eq. 1 below and expressed in kg/m³, where D is the apparent density (g/cm³), w is the weight (g/m²), and t is the thickness (µm):

$$D = (w/t) \times 1000 \tag{1}$$

The ISO 287 (2018) standard method was used to determine the amount of water contained in the laboratory-made paper, that is, the moisture content. According to the method, the weights of the conditioned papers and the weights of the oven-dried papers were determined and calculated according to Eq. 2 below. In Eq. 2, MC is moisture content (%), WC is the weight of the conditioned paper (g), and WO is the weight of the oven-dried paper (g):

$$\text{MC} = ((\text{WC} - \text{WO}) / \text{WC}) \times 100 \tag{2}$$

The surface gloss of all the produced laboratory-made papers was measured using a 60° glossmeter tester according to the ASTM 523 (2025) standard. The surface wettability and water retention properties of all the produced laboratory-made papers were evaluated using the Cobb test. Changes in the water holding capacity of the papers and the effect of the coated coating color were evaluated using the TAPPI T441 om-04 (2020) standard method. The papers produced and coated with a glossy coating color were sized using the apparatus on the head of the Cobb tester. Air-dry weights were determined using a precision balance and placed in a Cobb apparatus. Then, 100 mL of distilled water was added to the experimental setup to measure the water holding capacity. According to the standard, the test was completed within 60 s. The weight of the wet paper, which was kept in the Cobb test apparatus for a sufficient time and pressed, was measured again using a precision balance. The following Eq. 3 was used to calculate the water-holding capacity of the paper: where *a* is the air-dry weight of the paper (g) and *b* is the wetted weight (g) after the Cobb test application:

$$\text{Cobb} = 100 \times (b - a) \tag{3}$$

Data Analysis

The results were analyzed for statistical significance. The mean values and standard deviations were calculated, with the latter represented by the error bars in the figures. A linear regression analysis was used to determine the correlation between grammage and Cobb values, with the coefficient of determination (R^2) reported. Microsoft Excel was used for calculations, descriptive statistical analyses (mean, standard deviation, linear regression, R^2 values), and graph generation.

RESULTS AND DISCUSSION

Pulp Characteristics

Cellulose fibers were softened by soaking in pure water in accordance with the standards specified in the methodology section, subjected to mechanical beating, and pulp was obtained by removing the fine fibers with a laboratory-type fiber classifier device with an 80-mesh sieve opening. The data obtained as a result of the characterization of the pulp obtained are presented in Table 3.

Table 3. Characteristic Properties of Beaten Cellulose Pulp

Beaten Pulp Characteristics	
Schopper-Riegler Value (SR°)	Water Retention Value (WRV)
30	3.2

Structural Properties of Laboratory-made Base Papers

Data summarizing the qualities of laboratory-made papers used as base papers are given in Table 4.

Table 4. Structural Properties of Laboratory-made Pure Cellulose Uncoated (Base) Papers

	Grammage (g/m^2)	Thickness (µm)	Density (g/cm^3)	Moisture Content (%)
Mean Value	60.17	119.18	0.504	6.53
Std. Dev	0.75	2.00	0,004	0.33

Structural Properties of Coated Papers

The formulations of the twelve distinct coating colors are given in Table 1. These coating colors were applied to conditioned base papers at room temperature using a glass rod, in a semi-flowable form equal to 2 mL on both sides of each paper sample. After being left to dry at room temperature for 48 h, the coated papers were tested according to the standards specified in the methodology section to determine their grammage, thickness, density, moisture content, surface wettability, and water retention values, using the Cobb60 test method. Figure 2 shows the averages of the grammage, density, and thickness values of the paper samples, along with statistical error bars representing the standard deviation of ten individual specimen measurements under the same conditions.

According to the data in Fig. 2, the control sample (C), which was the uncoated paper, had a thickness of 119.2 µm, while an increase in thickness up to 141 µm was observed in the other paper samples after the application of the coating colors. This increase is attributed to a combination of factors: the physical deposition of the coating layer, the swelling of cellulose fibers due to water penetration from the coating formulation, and potential cockling of the sheet. Similarly, while the control sample (C) had a grammage of 60.2 g/m², the grammage values of the papers after coating varied between 66.1 g/m² and 69.1 g/m², confirming the add-on of coating solids. Paper coated with sodium polyacrylate-based coating colors (SP series) had a higher grammage value than other types of papers, suggesting a greater amount of coating solids was applied or retained. This implies that the coating color applied to the SP series paper was more concentrated and spread in a way that effectively filled the pores on the paper surface. These changes in thickness and grammage values have a direct impact on the density of the papers. The fact that the density decreased for all coated samples despite the increase in grammage indicates that the volumetric expansion (from fiber swelling and structural deformation) was more significant than the mass added by the coating. This is a well-known effect when applying water-based coatings to dry paper. Therefore, while the SP coating resulted in a higher solid add-on (as seen in the grammage), its interaction with the paper substrate still led to a net decrease in density compared to the uncoated control one. The observed decrease in density for the MS coating color coated papers, as seen in Fig. 2, is attributed to a foaming effect that introduces micro-porosity into the paper fiber structure, thereby reducing its overall density.

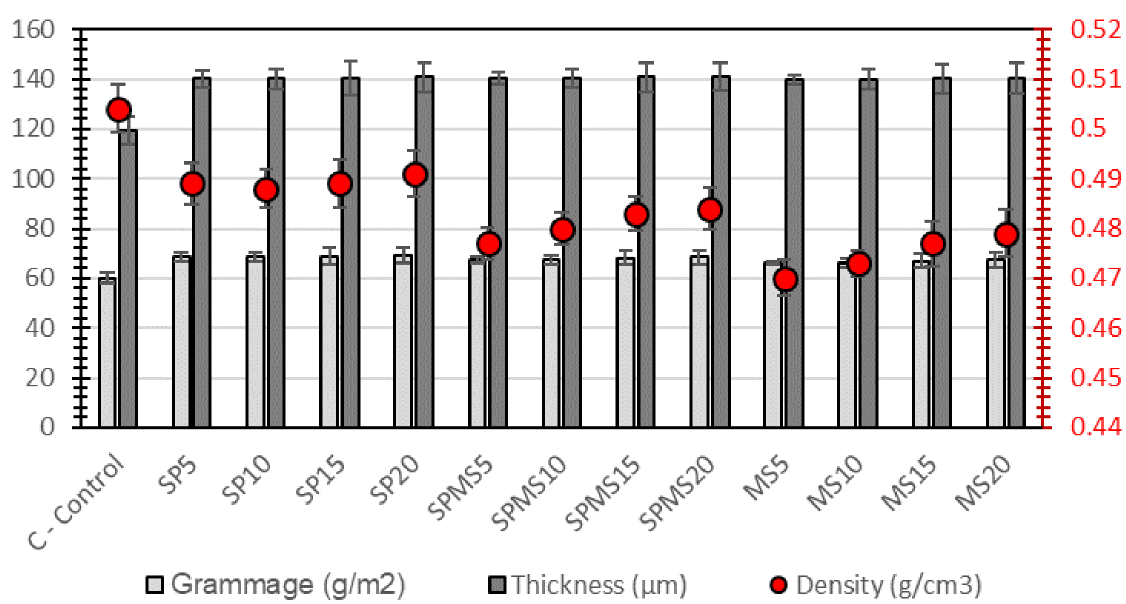

Fig. 2. Structural characteristics of paper groups

Figure 3 shows the Cobb60 (g/m^2) and moisture content (%) values of paper treated with different concentrations (5%, 10%, 15%, and 20%) of SP, SPMN and MS coating colors.

The results in Fig. 3 show that there was a noticeable increase in water retention capacity with increasing sodium polyacrylate concentration. Because the Cobb value of sample SP20 was 28% higher than that of the base paper that had not undergone coating highlights the effect of applying SP as a coating color. However, as the concentration in the coating colors increased, it became more difficult to achieve a homogeneous distribution on the paper surface. The data obtained show that the water absorbency value of the paper changes as the concentration and content of the coating colors change. The control group (C) represents the Cobb value of the base (C) paper without any coating applied. An increase in Cobb values was observed in papers treated with coatings containing specific SP content, while the opposite change was observed in papers treated with coatings containing MS content.

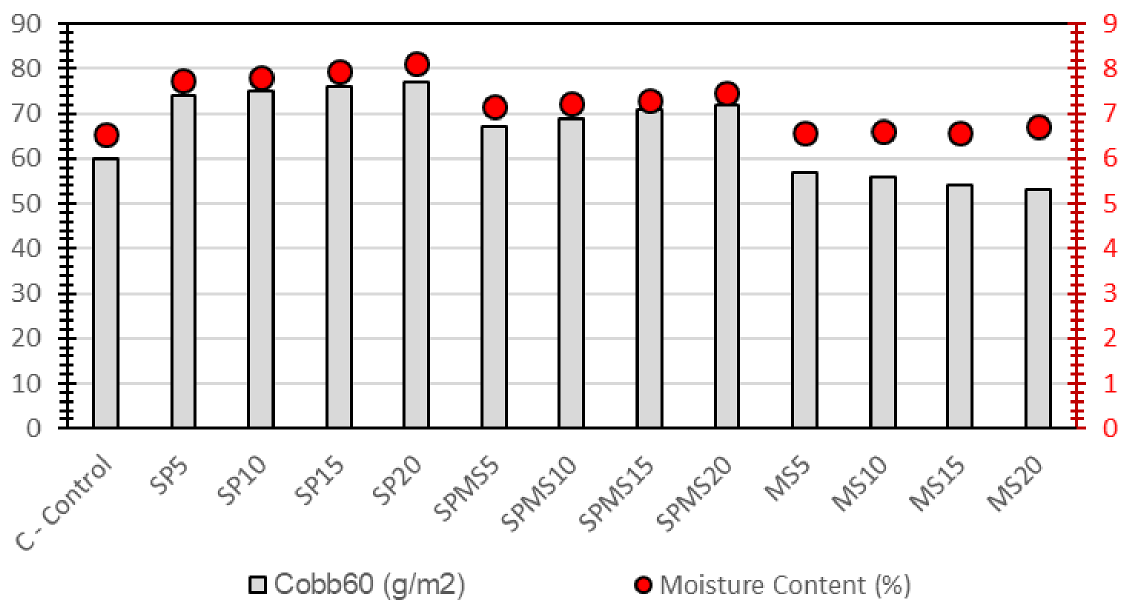

Fig. 3. Cobb60 and moisture content values of paper groups

To visually analyse the change in the surface wettability and water retention values of the papers depending on the coating color, the results are also presented in graph form in Figs. 4 to 6.

The data in Fig. 4 demonstrate a clear trend of relationship between increasing Cobb values with higher grammage and sodium polyacrylate (SP) content. This is directly illustrated by the specimen sequence from SP5 to SP20. This trend line shows that the water absorption for SP20 was markedly higher than that of SP5, pointing to the impact of the superabsorbent polymer. The primary reason for this increase is the characteristics of SP: As the formulation advances from SP5 to SP10, SP15, and finally SP20, the content of superabsorbent particles within the paper network rises. This fact leads to greater water retention by the polymer, forming a gel-like structure. The consistent upward trend confirmed by the regression analysis indicates that the elevated Cobb value is a direct and predictable outcome of the increasing SP content in the coating color, rather than a result of increased porosity. The results for SP5, SP10, SP15, and SP20 collectively demonstrate the effectiveness of the SP coating composition.

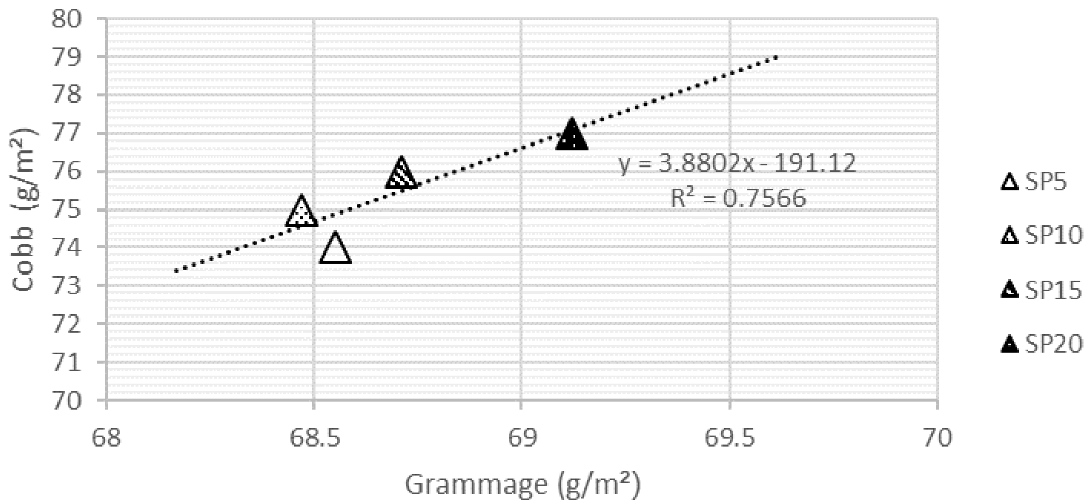

Fig. 4. Cobb values of paper treated with sodium polyacrylate-based coating color

The results given in Fig. 5 demonstrate a strong positive correlation between grammage and the Cobb value for the SP-MS coated papers, according to the trendline belonging to SPMS5 to SPMS20 specimens. The high R^2 value of 0.9257 confirms a reliable linear trend where increasing grammage directly corresponds to the water absorption ability of a specimen. This coherent rise from SPMS5 to SPMS10, SPMS15, and SPMS20 can be attributed to the synergistic effect of the coating contents. The sodium polyacrylate (SP) performs as a superabsorbent polymer, whose concentration increases with grammage, while the mixed starch (MS) acts to create a more porous structure that facilitates water penetration. Eventually, the highest Cobb value observed for SPMS20 was a direct result of the synergetic interaction of the SP-MS combination on water-retentive and structural effects at a higher grammage specimen.

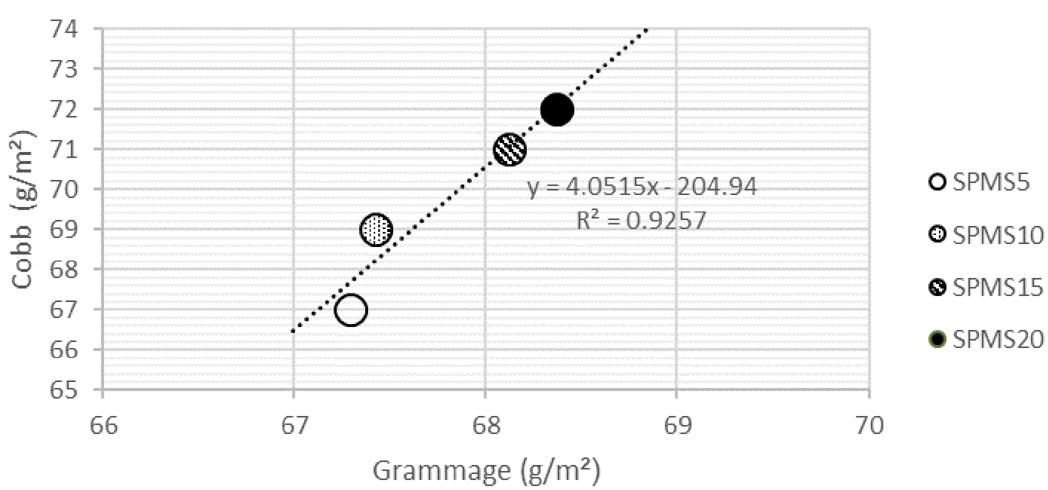

Fig. 5. Cobb values of paper treated with sodium polyacrylate and mixed starch-based coating color

In general, it can be interpreted that the surface roughness decreases and the surface gloss increases as the solid content of the coating colors increases (Lehtinen 1999).

The findings in Fig. 6 reveal a strong negative correlation between grammage and the Cobb value for the MS (Mixed Starch) coated papers, as clearly demonstrated by the performance of specimens MS5, MS10, MS15, and MS20. This inverse relationship (R^2 = 0.9851) indicates that water absorption consistently decreases as grammage increases among the group of specimens. The result for MS20 showed the lowest Cobb value, indicating the highest water resistance, while MS5 exhibited the highest absorption. This trend is a direct result of using MS, and it is the fact that it acted just like a filler. At higher grammages, as seen in MS15 and MS20, the MS effectively filled the pores within the paper network, creating a denser layer on the surface. This layer reduced pathways for water penetration, thereby enhancing water resistance and leading to the observed decrease in the Cobb value within the MS-coated paper groups.

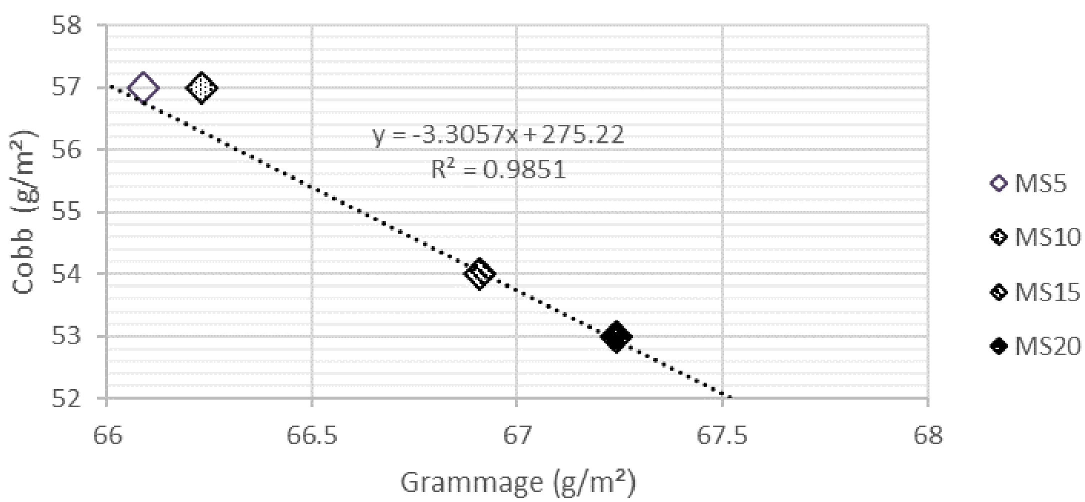

Fig. 6. Cobb values of paper treated with mixed starch-based coating color

Surface gloss of paper is generally proportional to the smoothness and porosity of the paper. To visually analyze how these properties change depending on the coating color type, the gloss values of the papers are presented in graph form in Fig. 7. In general, it can be interpreted that the surface roughness of the solid content in coating colors decreases and the surface gloss increases.

As shown in Fig. 7, base papers that had not been coated exhibited the highest surface gloss values. The gloss values of uncoated and coated papers with coating colors containing SP, SPMS, and MS substances at concentrations of 5%, 10%, 15%, and 20% were measured at a 60° gloss angle. The surface gloss is a critical property that can change, depending on the structure and porosity distribution of the surface of the paper. By application of coating process, the surface of paper has less pores and smoother appearance, which affects the gloss value of the paper. This uniform and non-porous surface, where the angle of incidence of light is equal to the angle of reflection, leads to higher gloss. The data in Fig. 7 show that formulations with the highest concentration of coating compounds (SP20 and MS20) generally had the highest gloss levels. This can be explained by the idea that by filling the pores and creating a smooth layer on the paper. Thus, more coating material results in improved surface coverage. However, an important exception was observed in the samples coated with coating colours having 20% dry matter (SP20, MS20, and SPMS520 series). These specimens had lower gloss values than those coated with dry matter coating colors of 5, 10, and 15%. Despite having high dry components, these samples did not reach the higher gloss peaks that had been expected. The reason for this is likely related to the component interaction of SP and MS, which can lead to increased surface roughness at the microscopic level. The SP particles may interfere with the ability of the MS particles to create a continuous, smooth surface. Instead of filling pores synergistically, the mixture might result in a less homogeneous surface with slight imperfections that scatter light, thereby reducing the specular reflection and measured gloss. This demonstrates that merely increasing the dry content in the coating color is insufficient; attaining ideal surface qualities depends on the components' chemical and physical compatibility.

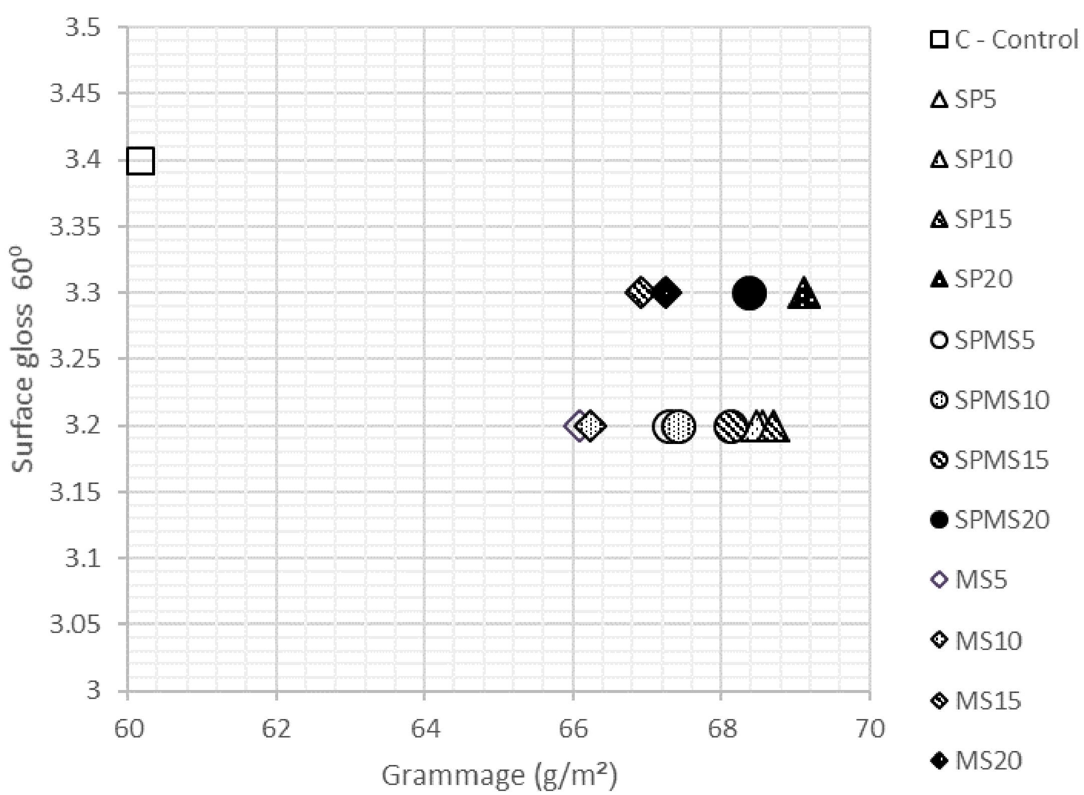

Fig. 7. Cobb values of paper treated with mixed starch-based coating color

The surface gloss data were correlated with the surface structure and porosity of paper groups, which were also assessed by the Cobb test. The Cobb test results quantify water absorption, where a lower Cobb value indicates a hydrophobic, less porous, well-coated surface, and a higher value indicates a hydrophilic, porous surface. The MS groups gave rise to an ideal coating behavior, where increasing grammage led to a sharp, linear decrease in Cobb value ($R^2 = 0.9851$) and a corresponding increase in gloss. This indicates that the MS coatings efficiently filled surface pores and created a denser structure on the surface layer, and hence, these MS coatings enhanced both smoothness for light reflection and barrier properties against water. However, grammage and Cobb value were positively correlated in the SP groups (R2 = 0.7566), indicating that while higher starch contents may improve gloss considerably, they may also cause swelling or a more hydrophilic fiber network that marginally reduces water resistance. The gloss values of the SPMS groups can be explained by the high positive connection between grammage and Cobb value (R^2 = 0.9257), which indicates that water absorption rose with increasing coating colour content. The SP and MS components' incompatibility probably resulted in a heterogeneous, microporous surface structure that did not effectively overlap the paper surface. This microstructure shows that increasing the color content of the coating is ineffective if the components do not work together to form a coherent, coated surface. This is because it scatters light, decreasing gloss, and creates channels for water penetration, thereby increasing the Cobb value.

This study investigated the effect of coating colors containing sodium polyacrylate (SP) and mixed starch (MS) applied to paper surfaces in different formulations on the physical and structural properties of the paper. The research results are consistent with related studies in the literature and are presented in the following paragraphs.

The Cobb value, which was determined for each paper type during the project study, is a parameter that measures the paper surface's water absorption capacity; a high value indicates that the paper can absorb more water. One of the study's main findings is that sodium polyacrylate-containing coated colors prepared at various concentrations improved the paper's water retention capacity and surface wettability, *i.e.*, the material's hydrophilicity.

These findings should be incorporated into design parameters during production, particularly paper types that may be used in wet or humid environments. Furthermore, this situation emphasizes the need for additional research into the synergistic effects of mixed starch and sodium polyacrylate compositions, as well as various formulations (Fig. 5).

In the future, a more detailed examination of the synergistic effects of mixed starch and sodium polyacrylate compositions will enable the development of more efficient and specialized paper grades. Additionally, when examining the structural and physical properties of the paper, it was found that structural properties, such as grammage, thickness, and density did not exhibit unexpected changes after the coating process. However, the impact of these results on the mechanical strength of paper has not been evaluated, which could be the subject of a future study.

CONCLUSIONS

The key findings of this study on the surface treatment of laboratory-made papers with coating colors containing sodium polyacrylate (SP) and mixed starch (MS) were:

1. The coating colors application increased thickness and grammage values of the papers due to solids addition and fiber swelling. SP-series coatings exhibited a higher grammage, which was associated with greater pore filling, while MS-series coatings had a lower density, which was attributed to a foaming effect.
2. The relationship between coating composition, grammage, and water absorption (Cobb value) was influenced by the components of the coating color. SP-coated papers showed increased water absorption with higher grammage due to superabsorbent properties of SP. Meanwhile, MS coated papers displayed reduced water absorption because of pore-filling. SPMS-coated papers exhibited a

synergistic effect, where increased grammage leads to higher absorption, merging SP's water retention with MS's porous structure.

3. The gloss values showed that the high-concentration coatings MS20 and SP20 increased the surface gloss of coated papers by creating a smoother surface. However, the SPMS-coated papers had a rough, heterogeneous structure that reduced gloss. The results confirm that optimal gloss depends not just on coating content but critically on the compatibility of the coating components.
4. These findings provide insights for designing specialized absorbent papers for wet/humid environments, though further research is needed on the synergistic effects of combined SP and MS.

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