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# Water-resistant kraft paper with different content of starch coated lightweight packaging application.

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# DECLARATION

I declare that this thesis entitled "Water-resistant kraft paper with different content of starch coated lightweight packaging application" is the results of my own research except as cited in the references.

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**Water-resistant kraft paper with different content of starch coated lightweight packaging application.**



## ABSTRACT

Paper packaging such as boxes, corrugated cardboard, have the disadvantage of being difficult to water resistance. The water resistance coating can effectively make up for this shortcoming. At the same time, starch-based modified starch coating is also one of the solutions to achieve water resistance goals. However, different types of starch coating have slightly different water resistance capabilities. This article aims to study the effects of different starch-based modified starch coating and coating thickness on water resistance capabilities. Modified starch is made from corn, wheat, potato, and cationic starch mixed with polyvinyl alcohol and then sprayed on kraft paper. The physical and mechanical properties, air permeability, and contact angle are tested in accordance with TAPPI and ISO standard. The 3-layer cationic modified starch coating achieves minimum air permeability, and the mechanical properties are also significantly improved, but the contact angle is not much different from other samples. In summary, the film-forming ability and low air permeability of cationic modified starch have the potential for high water resistance performance.

Keywords: Water resistance, spray coating, starch, polyvinyl alcohol, mechanical properties

**Kertas kraft bertahan air dengan pelbagai kandungan kanji yang dilapisi untuk aplikasi pembungkusan ringan.**


## ABSTRAK

Pembungkusan kertas seperti kotak, kadbod bergelombang, mempunyai kelemahan ketahanan air yang sukar. Penyalutan ketahanan air dapat secara berkesan mengatasi kekurangan ini. Pada masa yang sama, penyalutan kanji yang terlah diubahsuai juga merupakan salah satu penyelesaian untuk mencapai matlamat ketahanan air. Walau begaimanapun, pelbagai jenis penyalutan kanji mempunyai keupayaan ketahanan air yang sedikit berbeza. Artikal ini bertujuan untuk mengkaji kesan penyalutan kanji yang telah diubahsuai berasaskan kanji yang berbeza dan ketabalan penyalutan ke atas keupayaan ketahanan air. Kanji yang diubahsuai diperbuat daripada jagung, gandum, kentang, and kanji kationik yang dicampur dengan polivinil alkohol dan kemudian disemprotkan ke atas kertas kraft. Sifat-sifat fizikal and mekanikal, kebolehpenetratan udara, dan sudut sentuh diuji mengikut piawaian TAPPI dan ISO. Penyalutan kanji kationik yang diubahsuai tiga lapisan mencapai kebolehpenetratan udara minimum, and sifat-sifat mekanikal juga meningkat dengan ketara, tetapi sudut sentuh tidak banyak berbeza daripada sempel lain. Secara keseluruhan, keupayaan pembentukan filem dan kebolehpenetratan udara rendah kanji kationik yang diubahsuai mempunyai potensi untuk prestasi ketahanan air yang tinggi.



Kata kunci: Ketahanan air, penyalutan sembur, kanji, polivinil alkohol, sifat-sifat mekanikal

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CHAPTER 1

# INTRODUCTION

## 1.1 Background of Study

Packaging technology, especially cardboard, was needed in the online shopping era to pack parcels (Deshwal et al., 2019). However, the cardboard service life was shorter than plastic bags or bubble wrap. Because the cardboard was facing the defect: absorbent of moisture, this will make the cardboard quickly become softened when frequently absorbent and drained water in the Asian weather. But plastic materials have more severe defects which are destructive to the environment. Because plastic will break down into smaller pieces of microplastic by nature, and those microplastics will invade the human food chain. The observation starting from the 1950s shows only 9% of the plastic produced by humans has been recycled. Those facts prove that massive plastic waste cannot be controlled and might have a high possibility of affecting human beings (Bhuyan, 2022).

Therefore, many countries have been actively promoting de-plasticization and finding alternatives to replace plastic in recent years. Paper products are a promising material in sustainable use and eco-friendly to replace plastic. The shortcomings of paper products should be discussed and resolved. The paper will absorb water because the paper product is made from fiber, which is massive fiber bonding to become paper. Fiber was pulping from the plants in function to transport moisture. And this is why paper can absorb water: the porous structure in fiber affects the paper absorbance. To increase the water resistance performance of paper, those porous should be blocked up to avoid moisture.

There are a lot of materials to block pores, yet the most eco-friendly is the starch-based material (Ni et al., 2018). Starch is a polysaccharide refined from plants with similar properties extracted from different plants. Starch can be found in corn, tapioca, potato etc. In 2022, the Cationic Starch Global Market Report showed $1.58 billion of cationic starch and growth to $1.66 billion in 2023. The report also expected the market to grow to $1.96 billion in 2027 at a compound annual growth rate (CAGR) of 4.3%. In the paper industry, modified starch such as cationic starch, pregelatinized starch, oxidized starch, and hydroxypropylated starch were commonly used in the paper coating. Those starches have the outstanding property of being water-resistant compared to normal starch. Which is suitable and with potential as raw material to produce lightweight packaging material.

These massive starches are mostly used in the pulp and paper industry. The starch can function as the bonding agent, flocculant and retention aid, binder of coating etc. Coating technology can combine the benefit of cardboard and starch. Coating technology is painting the starch on the cardboard surface and calling paper coating technology. The paper coating has three standard coating techniques: blade coaters, air knife coaters, and cast coaters. Each coating type can cause different average thicknesses and affect water-resistant performance. Indeed, the instrument and concentration of starch also differ in each coating type. The paper coating has one or two side coatings covering one or both sides of the paper. One side coating is to improve the printability, water resistance and barrier. Two side coatings are more present in the durability, stiffness, and glosses. And indeed, the two-side coating is more expensive and needs more processes than the one-side coating.

This study compares the different content of starch in paper coating with the best performance in water resistance. And determine the optimal thickness of starch to have excellent water-resistant properties without making the cardboard too heavy. The result will involve different starch content and assessing coating cardboard water resistant properties.

## 1.2 Problem Statement

With the advent of the internet, many new industries have also emerged due to new demands. One of the industries that significantly influence human life is online shopping. Online shopping not only changed the way of life of human beings but also made many sunset industries rejuvenate, such as the paper industry. The logistics industry needs a lot of paper to become packaging materials because packaging with paper is relatively universal in human history for packing tea, spices, food, and even coins. Human history has proved that paper has sufficient mechanical strength. And based on improving the industrial production capacity, paper is also becoming cheap because it is mass-produced. However, the porous properties of fibre-made paper are easily absorbed in moisture, and cardboard made from regular paper also inherits this weakness. This makes the paper packaging lose its function of protecting the goods once it encounters a humid environment. The paper packaging's mechanical strength decreases because the fiber becomes dispersion when the strong hydrogen bonds that bond the fiber destroy by moisture.

This defect is causing the logistics industry to use highly waterproof materials such as plastic, which cannot be degraded by nature. Using plastic can cause pollution to the human food chain. Therefore, the solution to solve paper in the poor moisture-resistant is essential to prevent more people from using plastic. At the same time, improving the water resistance of paper packaging can also improve the protection ability of the goods. This also allows the cardboard to perform better in a high-moisture environment. Paper material is also a part of the carbon cycle, ideally can accomplish zero carbon emissions, and is a great help to reduce the greenhouse effect.

Many scholars are researching blocking the pores or covering the paper's surface using unique materials to solve the weakness of the paper. One of the biodegradable and low-cost materials is starch. Starch is hydrophilic, but after heating with the cross-linking agent or chemical modification, it can create cross-links and make the starch improve water-resistance. Research from China proves polyvinyl alcohol (PVA) mixed with corn starch (CS) can produce a good moisture-resistance starch (Lin et al., 2017). However, this research did not research the different types of starch to replace corn starch, possibly causing a gap in water-resistance performance and, at the same time, applying the modification starch on the cardboard to determine optimal coated thickness with minimum weight to reach maximum water-resistance also a key of research.

## 1.3 Objectives

First Objectives: to compare different types of starch coated in water resistant.

Second Objective: to determine optimal coated thickness of starch with minimum weight to achieve maximum water-resistant.

## 1.4 Scope of Study

This research is searching about modified starch coating on corrugated cardboard. Which is related on the surface treatment only instead of the pulping formula or any cardboard making process. The film forming ability of modified starch is the key to research point to giving coating layer water resistance. Therefore, the tensile strength after coating modified starch will also be tested to prove modified starch can enhance the corrugated cardboard in many ways.

## 1.5 Significances of Study

This study will be researching the film forming ability for modified starch. This can be increasing cardboard moisture resistance without using any non-degradable materials such as PVC layer that commonly used in nowadays. The decrease of plastic materials will retard the microplastic pollution in global and increase the use limit of cardboard. The demand of virgin pulp will be affected and decrease, the forest that will be harvested will also decrease, eventually lead to retard the greenhouse effect.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

In this high-tech era, the presentation of information is migrated to the LCD from paper. But this doesn't mean paper has become useless; with the advancement of the construction design, printing technology, and transportation industry, the paper demand was continuously rising. Based on the data from the Statista Research Department (2023), 408 million tons of paper and paperboard have been consumed globally. The containerboard categories occupied 43.63% or 178 million tons of paper consumed. As estimated, the consumption will rise to over 220 million tons in 2032.

The trade volume of paper has risen. In addition to trying to transform the use of paper products due to countries' policies to reduce plastic waste, the characteristics of paper are the main reason for the increase in trade volume.

## 2.2 Paper product

Paper products such as printing paper, thermal paper, food packaging paper, containerboard, etc., make human life more convenient. Most paper products are biodegradable. Therefore, paper waste is more easily processed than plastic, which needs classification before being discarded. But, the paper also has a long recycle chain that can theoretically recycle at least four to 25 times (Eckhart, 2021). Therefore, paper products are commonly reused and are environmentally friendly. Compared to other materials, such as plastic, paper products are more convenient to repulp and mix with new virgin pulp to become recycled paper. Although, food packaging paper is harder to recycle based on the oil stain on the paper surface. But other products become the primary material to recycle. For example, paper and paperboard in the United States occupy 68 percent of the recycling rate in 2021 (Statista, 2023).

Besides, the porous structure of fiber in the paper is convenient for the designer to design the product detail on the paper product easily. The fiber-fiber bonding arrangement with a thin layer also allows the paper to reshape easily. Those abilities affect the division of labor in the paper industry finer. The paper mall focused on producing paper products, and the downstream focus was designing the painting. This will decrease the cost of investing in the paper industry and increase product quality.

On the other hand, the lightweight of paper also helps other industries, especially transportation. In transportation, the energy used and cost will increase based on the weight of the cargo. The heavier packaging material will cause the transportation process to need more power and produce more greenhouse gases. Therefore, the common packaging materials are paper-based and plastic-based. Also, the plastic is sturdier and more invulnerable; the paper has been corrugated to become stronger and sturdier, which is called corrugated cardboard.

### 2.2.1 Corrugated cardboard

Corrugation designs are common in human life, from packaging material, seashells, and sound-absorbing materials to transportation containers. This design was devised in 1856 by Edward G. Healy and Edward E. Allen to make lightweight and stiff materials to support the top hats more durable. And gradually develop into other fields with the application of human beings, especially for packaging material. The corrugation design can become more durable because the wavy shape makes the ridges and grooves distribute the load to the larger surface. This is like using a finger to compress the egg from top and bottom; it is more complicated than squeezing from beside. Therefore, the cardboard made from this design will increase stiffness and can bear heavier weight than itself.

Besides, corrugated also have many patterns that can affect their performance. They can identify two types, which are board styles and flute types. Board styles mean the layer of corrugated; for example, a double wall has three pieces of liner and two layers of corrugated between the liner. The flute types mean the corrugation height and classify as F flute, E flute, C flute, etc. The common flute type is the E flute, which is 1/16 inches corrugation height.

However, corrugated cardboard also has the weakness of paper, which is moisture absorbent. The fiber structure in the cardboard that is porous will absorb water. The standard solution to overcome this weakness in the paper industry is coating the cardboard surface with a moisture-resistant material, such as polyethylene (PE) and paraffin wax. Those materials can effectively block the porous fiber and increase the performance of corrugated cardboard.

## 2.3 Coating surface treatment

The coating surface treatment is a technique to coat material on the surface paper to enhance surface quality. This surface treatment can improve printability, protection against ultraviolet radiation, water resistance, mechanical properties, etc. In other words, the paper coating is a reinforcement to reduce the shortcoming of paper. This surface treatment is common in paper products, such as thermal paper, magazine paper, food packaging paper, and paper labels that are easy to find. For example, the thermal paper was coated with heat-sensitive material such as bisphenol A (BPA). When the paper is close to the heel will turn black color. Therefore, the merchant or seller that needs to print a lot of receipts can save costs in the printing process, compared to using a color printer that needs to pay the price of ink. Blade coaters, air knife coaters, and cast coaters are the three common methods of coating materials on paper surfaces.

### 2.3.1 Blade coating

The blade coating also called the doctor blade coating method, uses a sharp blade to lay an average layer of coating materials in liquid form (Cherrington & Liang, 2016). This coating method will create a smooth surface, but the junction of materials and paper will become uneven. This result is because the surface of the based paper is uneven; the sharp blade only scrapes the surface of the materials and lets the materials self-infiltration to the irregular rough surface of the based paper. Therefore, the thin coating materials will be found in the protruding part, and the thick layer will be found in the concave portion of the based paper surface.

### 2.3.2 Air knife coater

Air knife coaters are the methods using a unique design air knife that can control the pressure of gas to blow the liquid materials more advantage (Shim, 2013). Compared to blade coating, air knife coaters parallel the surface of liquid materials and based paper. This means liquid materials' protruding and concaving parts are the same as the based paper. Therefore, liquid materials should use low solids or viscosity to ensure effectiveness. The surface of the final product might be uneven, but the absorbent of ink is like standard paper because the ink can penetrate the hollow surface.

### 2.3.3 Cast Coater

Cast Coater, compared to other methods, is more expensive and complicated. First, a layer of liquid coating will be deposited on the base paper surface. Next, use the highly polished metal drum to press the surface. Finally, a high gloss paper will be produced. These methods are common to create high-quality photo paper.

## 2.4 Additive

The additive is the raw material combined with paper, increasing paper performance. The materials mentioned above, such as polyethylene and paraffin wax, were a type of additive. Additives can be classified as papermaking additives and surface treatment additives. Papermaking additives are chemical additives that mix with pulp before making paper. The surface treatment additives are used to coat the paper. Their difference was that papermaking additives increase the paper quality, such as brightness and strength. And for surface treatment, additives highly increase the paper's performance for special purposes, such as thermal paper or water resistance.

### 2.4.1 Starch and modified starch

Starch is one of the additives commonly used in the paper industry. It can be used as a bonding agent or adhesive to increase the fiber-fiber bonding as a papermaking additive. Starch also can function in the surface sizing or coating to increase the printing performance. The common starch used in the paper industry is corn starch, which will be mixed with other materials to become modified starch before being processed in the paper products. Although different starch, such as corn and wheat starch, have similar properties, this tiny gap might have a massive performance after processing as modified starch. Some common uses of modified starch in the paper industry are cationic starch, oxidized starch, hydroxyethyl starch, etc., which have different ratios with starch and other chemicals.

### 2.4.2 Polyvinyl alcohol

Polyvinyl alcohol (PVA) is a biodegradable material made from polyvinyl acetate through hydrolysis. However, the degradable rate is slow in the natural environment because the PVA degradable is based on the microorganism through an enzymatic process. Based on the new research, polyvinyl alcohol and cornstarch (PVA/CS) have better water resistance with slightly lower paper tensile properties and stiffness (Lin et al., 2017). This is because the PVA can significantly improve the film-forming ability of starch and fully cover the porous in the paper.

## 2.5 Physical and mechanical properties test (maybe need to rewrite)

### 2.5.1 Thickness and grammage

Thickness and grammage important in the paper industry for identify paper type and application. For example, the tissue paper was thinner, and less weight than writing paper. Thickness and grammage was a physical property test for identify paper how thin or thick and in this research, also help to identify the coating thickness that can reach moisture resistant effect. The thickness was measured using caliper, and the formula to calculate grammage was divided paper weight by area of paper in the square meters. (Lahti et al., 2020) The coating thickness was the paper thickness after coating minus before coating.

### 2.5.2 Tensile test

Tensile test was using the tensile test machine, or also call universal testing machine (UTM) to test the tensile strength of paper can bear until the paper been pull apart into two pieces. Based on the TAPPI T 494, the UTM machine operated with two clips clamped a sheet of paper, and sustained application tension until the paper pull apart. The force will be recorded when the paper been destroyed and show in Newton meter per gram (Nm/g) (Mejouyo et al., 2020). Tensile test can help people know how much tension of the paper can take and make decision if want using paper as packaging materials.

### 2.5.3 Burst test

Burst test was to test how many pressure that the paper can bear before rupture. According to TAPPI T 403, the burst strength tester was using in this test, with clamped by the machine, and bottom of the paper have the rubber membrane was sustained increase the pressure to extrusion the paper until rupture. Same as the universal testing machine, the rubber membrane pressure will be recorded but in the kPa $m^2/g$ unit. Burst testing simulates conditions that packaging paper encounters during shipping like handling, loading, and unloading. The relates of the burst strength and tensile strength are effect by the fiber-fiber bonding, fiber strength, and the fiber thickness.

### 2.5.4 Air permeability test

Placing paper or any clothing materials in the air permeability tester to test and record how much volume of air passes through the material called air permeability test according to ISO 5636-3. The strength of air permeability has a direct impact on the pores of the material. For example, cloth materials were higher air permeability than paper materials because cloth materials have more pores than paper materials. Therefore, the air permeability is also indirectly related to the moisture resistance ability of the materials. This is because the capillary action will lead the porous materials been penetrated faster. The standard of air permeability test in this research according to ISO 9237:1995. (Filipova et al., 2020)

### 2.5.5 Water drops test.

Water drops test also name contact angle test. According to ISO 14778:2021 is a mechanical test to measure the contact angle of materials surface to the liquid. A drop of water will be dropped on the material surface and a camera need to record all the process to measure the contact angle. Contact angle is the angle from baseline to the droplet contour. The theory of contact angle is the highest contact angle, the lower of surface energy (Krainer & Hirn, 2021). In addition, the lower surface energy effect the materials less absorb the moisture. Therefore, the water drops test can identify the ability of the material to absorb moisture.

### 2.5.6 Statistical test

Statistical test was using computer software to calculate the significance different is significant or not significant between the results using different types of calculated methods. By comparing different results one by one to calculate the statistical significance between them, assuming that the result is lower than the selected significance level, then there is a significant difference between the results. And if it is higher than the significance level, there is no significant difference.

# CHAPTER 3

# MATERIALS AND METHODS

## 3.1 Materials

### 3.1.1 Chemical

The chemicals used in the experiment are Polyvinyl alcohol $(C_2H_4O)x$ from R&M Chemicals company, Corn starch, Potato starch, Wheat starch brand by Cap

Bintang from Lazada – Great Ocean Dried Seafood, and Cationic starch from local industry. The modified starch deployment process used the PVA and all types of starch.

### 3.1.2 Apparatus

The apparatus that will be used in the experiment are a beaker, label sticker, glass stirrer, sprayer, timer, tissue, Cobb test machine, pipette, timer, tensile test machine, and electrical scale. Krafting paper from the local industry replaced the corrugated cardboard material as a coating solution carrier.

## 3.2 Methods

The experiment's target is to coat corrugated cardboard with different types of modified starch and test the moisture resistance and tensile strength of corrugated cardboard after coating to research the objective. Besides, the coating solution and layer will be abbreviated as shortening in the table below.

**Table 3.1: Abbreviation the coating solution and layer**

| Treatment level | Shortening |
|---|---|
| Polyvinyl alcohol mixed with corn starch coating in 3 layers / 6 layers. | PVA/CS_3L / PVA/CS_6L |
| Polyvinyl alcohol mixed with wheat starch coating in 3 layers / 6 layers. | PVA/WS_3L / PVA/WS_6L |
| Polyvinyl alcohol mixed with potato starch coating in 3 layers / 6 layers. | PVA/PS_3L / PVA/WS_6L |

| | |
|---|---|
| Polyvinyl alcohol mixed with cationic starch coting in 3 layers / 6 layers. | PVA/CAS_3L / PVA/CAS_6L |

### 3.2.1 Deploy modified starch.

Weighted 30 grams of PVA and 15 grams of corn starch into two different 500 ml beaker. Deploy the PVA with 450 ml distilled water and bath in the 1L beaker on hot plate, heat the beaker in 95°C and continue stirred the PVA solution for 30 minutes. Replaced the PVA solution beaker with corn starch beaker, mixed the corn starch with 185 ml distilled water and decrease the hot plate to 90°C. Stirred the corn starch solution for 40 minutes. Those two solutions were poured into the 1L beaker and continue stirred for 20 minutes in the room temperature to deploy PVA/CS modified starch solutions (Lin et al., 2017). Repeated the whole process by replacing the corn starch to wheat starch, potato starch and cationic starch to deploy PVA/WS, PVA/PS, and PVA/CAS modified starch solution.

### 3.2.2 Coating process

Stick 5 sheet of the kraft paper (160 gsm in A4 size from Dr Boon) vertically to a vertical board with clay (Faber Castell tack it). Poured PVA/CS solution into the paint spray gun (GS Optimus F-75S), keep the distance of paint spray gun and the paper for 30 – 40 cm and spray the solution on the kraft paper by left to right and from top to bottom. Each sheet of paper was using 15 to 20 second for a single layer spray. Dried the coating solution used hot air gun (Stanley STXH2000) for 2 minutes at 100°C with second gear and keep the distance in 5 – 10 cm (Khansary et al., 2014). Repeat the spraying and drying process until the target layer (3 and 6 layers, each layer has 5 sheet). Air dried the paper when reach last layer for 10 minutes. Repeat the coating process to achieve the target paper coating solution (PVA/WS, PVA/PS, and PVA/CAS).

### 3.2.3 Prepared testing sample

Re-cut the A4 coated paper to the size required for the next test using a paper cutter (Astar Paper Cutter W0912). The paper was segmented to tensile test (1.5*10 cm), burst test (5*5 cm), and water drop test (10*10 cm). Used 2B pencil (Stabilo 2B pencil) draw an outline of size required for the test, each testing outline had 1 cm distance to other, and random the location of the outline.

### 3.2.4 Thickness and grammage

The PVA/CS_3L sample was placed into the Thickness test machine (ISO 534 Electronic Paper Thickness Meter), and the machine was run to record the results. The sample sizing and weight were measured using a digital calliper and electrical scale. The sample thickness and grammage were calculated using the gsm formula (Equation 3.1). The process was repeated for all samples mentioned in Table 3., and each sample had three replicates from different sheets of coating paper. The thickness and grammage tests were conducted according to ISO 534 (Todorova et al., 2021).

$$gms = \frac{weight}{length*width} \qquad \text{Formula 3.1}$$

### 3.2.5 Air permeability, tensile test, and burst test.

Air permeability test was done according to ISO 5636-3, the PVA/CS_3L sample were place in air permeability tester (GBPI, Paper and Board air permeability tester), run the machine and record the results (ml/min) (Filipova et al., 2020).

Tensile strength was done according to TAPPI T 494, clamped the sample at the two clips on universal testing machine (QC-513B2 UTM). Run the machine until the sample been pull apart and record the results in Newton meter per gram (Nm/g) (Mejouyo et al., 2020).

Burst strength test was conducted according to TAPPI 403, clamped the sample on the Burst strength tester (Mullen method). Run the machine, wait the sample breaks by the compressed membrane and record the result (kPa $m^2/g$) (Pego et al., 2020).

The testing were repeated for all sample in Table 3.1, and each sample had three replicates from different sheet of coating paper.

### 3.2.6 Water drops test

Sample were horizontal placed in front of the camera, and the camera focal length was on the center of the sample. Dropped a drop of water at the center of sample and recorded the whole process. Used the image processing software (ImageJ) to measure the contact angle and record the results (Krainer & Hirn, 2021). Repeat the process to all sample mentioned in table 3.1, and each sample had three results from different sheet of coating paper.

### 3.2.7 Statistical test

A significance level of 0.05 was used with the Tukey HSD one-way ANOVA post hoc test in conjunction with the SPSS (Statistical Package for the Social Science) software. All results were tested against other groups, considering significance for values less than 0.05 and non-significance for value greater than 0.05. All results were expressed as mean ± SD.

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 Physical Properties

### 4.1.1 Paper thickness and grammage

**Table 4.1: Physical properties of coating paper coated with different coating solutions and layer numbers.**

| Coating solution | Paper thickness, mm | Paper grammage, gsm |
|---|---|---|
| PVA/CS 3L | $0.3498 \pm 0.0288_{a}$ | $269.60 \pm 9.84_{ab}$ |
| PVA/CS 6L | $0.4048 \pm 0.0075_{b}$ | $299.99 \pm 3.53_{c}$ |
| PVA/WS 3L | $0.2861 \pm 0.0069_{cd}$ | $202.33 \pm 4.18_{d}$ |
| PVA/WS 6L | $0.4162 \pm 0.0070_{b}$ | $286.65 \pm 9.09_{bc}$ |
| PVA/PS 3L | $0.3130 \pm 0.0131_{ad}$ | $225.66 \pm 7.83_{ef}$ |
| PVA/PS 6L | $0.3153 \pm 0.0186_{ad}$ | $232.83 \pm 11.30_{f}$ |
| PVA/CAS 3L | $0.2585 \pm 0.0050_{c}$ | $211.74 \pm 7.66_{de}$ |
| PVA/CAS 6L | $0.3237 \pm 0.0119_{ad}$ | $256.15 \pm 4.31_{a}$ |
| CONTROL | $0.2169 \pm 0.0038_{e}$ | $166.48 \pm 0.98_{g}$ |

Different letters within the same column are statistically significant difference at $\alpha = 0.05$.

Table 4.1 show the physical properties of coating paper that coated with difference formula of coating solution and difference coating layers. It is obvious from the table that as the number of coating layers increases, the thickness and grammage of the paper also increases. There is a positive correlation relationship between the number of layers and paper physical properties.

The mean thickness of different coating layer was in the range of 0.2861 – 0.3498 mm for 3 layers coating and 0.3153 – 0.4162 mm for 6 layers coating. As the number of coatings increases, the thickness of the paper also increases. This means that all modified starches have some film-forming ability, but the film-forming ability varies with the types of modified starch (Hernandez-Perez et al., 2021). For example, only potato modified starch is not significant different between 3 layers and 6 layers, the other modified starch has significant different between different layers. Among them, the most obvious difference is wheat modified starch that have 0.13 mm different in mean, second is the cationic modified starch that have 0.07 mm different and third is corn modified starch in 0.05 mm different.

For the mean grammage of different coating layer was in the range of 202.33 – 269.6 gsm for 3 layers coating and 232.83 – 299.99 gsm for 6 layers coating. The result of grammage test is like the thickness test that the potato starch also not significant different between 3 layers and 6 layers. Therefore, the grammage and thickness of coating are also positively correlated.

From Table 1, corn and wheat modified starch may have the greatest film-forming ability in this research. Cationic modified starch had the second strongest film-forming ability, and potato starch was weakest. However, since it is impossible to calculate the coating solution used for each layer of coating to be average, it is also possible that dust and wood particles in the air adhere to the coating in the coating process, resulting in a thicker coating. Or the quality of the compressor and the operation coating of the tester will also affect whether the spray gun can spray the coating solution evenly.

This also may be because the amylose and amylopectin ratio of wheat starch affect the film-forming ability in the deploying process. Compared to Hernandez-Perez thesis, he provides the evident about ratio of amylose and amylopectin affected film-forming ability by higher ratio of amylose, higher of film-forming ability (Hernandez-Perez et al., 2021). Because wheat starch used in this thesis was a normal food grade starch, it should assume ratio of amylose and amylopectin in 25% amylose and 75% amylopectin. In this low proportion of amylose, wheat modified starch can reach such a thick thickness compared to other types of modified starch, which can directly prove that the conjecture that the sample is contaminated is very likely.

### 4.1.2 Air permeability test

**Table 4.2 Air permeability of coating paper at different coating solution and layer numbers.**

| Coating solution | Paper thickness, mm | Air permeability (ml/min) |
|---|---|---|
| PVA/CS 3L | $0.3498 \pm 0.0288_{a}$ | $90.00 \pm 26.46_{a}$ |
| PVA/CS 6L | $0.4048 \pm 0.0075_{b}$ | $23.33 \pm 05.77_{b}$ |
| PVA/WS 3L | $0.2861 \pm 0.0069_{cd}$ | $80.00 \pm 20.00_{ac}$ |
| PVA/WS 6L | $0.4162 \pm 0.0070_{b}$ | $20.00 \pm 00.00_{b}$ |
| PVA/PS 3L | $0.3130 \pm 0.0131_{ad}$ | $50.00 \pm 10.00_{bc}$ |
| PVA/PS 6L | $0.3153 \pm 0.0186_{ad}$ | $43.33 \pm 05.77_{b}$ |
| PVA/CAS 3L | $0.2585 \pm 0.0050_{c}$ | $20.00 \pm 00.00_{b}$ |
| PVA/CAS 6L | $0.3237 \pm 0.0119_{ad}$ | $20.00 \pm 00.00_{b}$ |
| CONTROL | $0.2169 \pm 0.0038_{e}$ | $423.33 \pm 05.77_{d}$ |

Different letters within the same column are statistically significant difference at $\alpha = 0.05$.

Table 4.2 presents about the air permeability of coating paper at different coating solution and layer numbers. The air permeability mean of different coating layers was 20 – 90 ml/min at 3 layers and 20 – 43 ml/min for 6 layers. And all modified starch coatings were less air permeability compared to control group. All coating samples were dropped to below 100 ml/min from 423.33 ml/min. At the same time, it has also been concluded that the more coating layers, the less air permeability to the sample (Koppolu et al., 2019), until reach the limit of the air permeability testing machine (20 ml/min).

For the comparison of different modified starches, cationic starch has the worst air permeability among all starches. It has the property of minimizing air permeability when it is coated with three layers. Among the 6-layer coatings, cationic and wheat modified starch has the lowest air permeability, while corn modified starch has higher air permeability than wheat. Therefore, in terms of air permeability, the cationic starch coating can be the least porous coating solution that can achieve the lowest air permeability performance with the fewest layers of coating.

Moreover, since air permeability refers to the ability of air to pass through a material, a reduction in air permeability can also effectively reduce the penetration of water vapor through the material (Li et al., 2019), so air permeability can also be regarded as one of the factors affecting the water proofness of the material. In this test, cationic modified starch demonstrated potentially outstanding water-resistance properties.

## 4.2 Mechanical Properties

### 4.2.1 Tensile strength and Burst strength.

**Table 4.3: Tensile strength and burst strength of coating paper at different coating solution and layer number.**

| Coating solution | Paper thickness, mm | Tensile index (Nm/g) | Burst index (kPa $m^2$/g) |
|---|---|---|---|
| PVA/CS 3L | $0.3498 \pm 0.0288_{a}$ | $10.94 \pm 0.08_{ab}$ | $6.33 \pm 0.17_{ab}$ |
| PVA/CS 6L | $0.4048 \pm 0.0075_{b}$ | $10.98 \pm 0.45_{ab}$ | $6.46 \pm 0.06_{b}$ |
| PVA/WS 3L | $0.2861 \pm 0.0069_{cd}$ | $9.91 \pm 0.43_{a}$ | $5.92 \pm 0.08_{ac}$ |
| PVA/WS 6L | $0.4162 \pm 0.0070_{b}$ | $15.76 \pm 0.32_{c}$ | $7.35 \pm 0.30_{d}$ |
| PVA/PS 3L | $0.3130 \pm 0.0131_{ad}$ | $10.12 \pm 0.31_{a}$ | $5.95 \pm 0.07_{ac}$ |
| PVA/PS 6L | $0.3153 \pm 0.0186_{ad}$ | $10.07 \pm 0.16_{a}$ | $5.99 \pm 0.12_{ac}$ |
| PVA/CAS 3L | $0.2585 \pm 0.0050_{c}$ | $11.69 \pm 0.28_{b}$ | $6.52 \pm 0.11_{b}$ |
| PVA/CAS 6L | $0.3237 \pm 0.0119_{ad}$ | $12.03 \pm 0.93_{b}$ | $6.51 \pm 0.27_{b}$ |
| CONTROL | $0.2169 \pm 0.0038_{e}$ | $8.03 \pm 0.07_{d}$ | $5.72 \pm 0.08_{c}$ |

Different letters within the same column are statistically significant difference at $\alpha = 0.05$.

Table 4.3 presents about the tensile strength and burst strength of coating paper at different coating solution and layer number. As mentioned before, the burst strength was highly relevant to the tensile strength and should been present in one table together to make it easier to observe the connections between these two mechanical properties. The mean tensile strength of different coating layer was 9.91 – 11.69 Nm/g at 3 layers and 10.07 – 15.76 Nm/g at 6 layers coating. Theoretically, as the number of coating layer (thickness) increase, the tensile strength will also increase (Szlachetka et al., 2021).

The same situation also occurs in the burst strength, that is, the 6-layers wheat modified starch also has the highest improvement in the burst strength of paper. The mean burst strength of different coating layers was 5.92 -6.52 kPa $m^2$/g at 3 layers and 5.99 –

7.35 kPa $m^2/g$ at 6 layers. Tensile strength and burst strength after coating compared to uncoated kraft paper (CONTROL) did improve the mechanical properties, but contamination issues due to uncontrollable environmental factors during the coating process did hinder further comparisons.

But in Table 4.3, most of the modified starch coating solutions had no significant difference between different coating layers, even the coating layer had caused the thickness of paper to be significantly different. Only the modified starch of WS has a huge difference in tensile strength under the same formula but different number of coatings. Therefore, it is reasonable to suspect that the improvement of paper tensile strength by modified starch is limited, except for wheat modified starch. The thickness of CS and WS in the 6-layer coating are very similar, but there is a huge gap in tensile strength between them. The reason for this gap may be that certain characteristics of wheat starch produce better chemical reactions with PVA during the preparation process. But it is also possible that contamination during the experiment caused this batch of wheat starch-coated samples to produce better drawing strength.

## 4.3 Surface characterization

### 4.3.1 Contact angle

**Table 4.4 Contact angle of coating paper at different coating solution and layer number.**

| Coating solution | Contact Angle (°) |
|---|---|
| PVA/CS 3L | $71.2 \pm 28_a$ |
| PVA/CS 6L | $87.2 \pm 28_a$ |

| | |
|---|---|
| PVA/WS 3L | $69.6 \pm 13.8_a$ |
| PVA/WS 6L | $61.6 \pm 6.5_a$ |
| PVA/PS 3L | $60.2 \pm 9.6_a$ |
| PVA/PS 6L | $63.6 \pm 13.1_a$ |
| PVA/CAS 3L | $60.7 \pm 5.6_a$ |
| PVA/CAS 6L | $61.9 \pm 4.6_a$ |
| CONTROL | $76.2 \pm 2.5_a$ |

Different letters within the same column are statistically significant difference at $\alpha = 0.05$.

Table 4.4 show the contact angle of coating paper at different coating solution and layer number. The contact angle mean was on 60.2 – 87.2° and the difference between them is very insignificant even difference layers at same coating solution. The influence of different modified starch and number of layers on the contact angle cannot be observed without obvious differences. The reasons for these results may be because all types of modified starch cannot change the surface smoothness to decrease contact angle of the water. According to Table 4.3, the air permeability of the sample is reduced, but this does not mean that the surface is smooth. The contact angles displayed by the uneven coated surface and the uncoated surface are very close or unchanged.

Another possibility, as mentioned before, is that the sample contamination caused during the coating process causes the coating surface to be uneven, ultimately resulting in a contact angle that is no different from that of the uncoated sample. The last possibility is that errors in the measurement process led to inaccurate results. For example, the height of the dripping water droplets is not consistent, or the angle of the camera shooting the water droplets is not set correctly. Various factors directly or indirectly cause the experimental results to be unable to show which modified starch coating has a larger contact angle. Therefore, this test result cannot examine the modified starch coating's ability in water-resistance.

# CHAPTER 5

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusion

The effects of different starch-based modified starches and the number of coating layers on the physical and mechanical properties of kraft paper were studies. This study shows that the coating of cationic modified starch in three layers is thinner than most modified starch coatings, only 0.2585 mm and 211.74 gsm. At the same time, with such a thin coating, it can still withstand 11.69 Nm/g tensile strength and burst strength of 6.52 kPa $m^2/g$. At the same time, in the test of measuring air permeability to prove the reduction of paper pores, it also reached the mechanically detectable air permeability limit of 20 ml/min. Due to the shortage of time and funds, it is impossible to conduct a water absorption test, so the lower air permeability can only be used as indirect evidence to prove that the cationic modified starch coating has good waterproof properties.

## 5.2 Recommendations

For the future research, it is suggested that:

a. Control the timing of deployment PVA and starch. If conditions permit, simultaneous deployment can decrease the timing of the solution reacting with air. That makes the solution become solidification.

b. Control the coating environment in the better air quality without pollution particles or sawdust, to avoid pollution in the spray coating process, and the heat gun drying process.
c. Ensure the pressure of compressor in the spray coating process is even, to avoid the problem of reduced spray volume of coating liquid at relatively low pressure.
d. Use a spray gun that calculates the volume of liquid sprayed in real time to calculate the coating volume used for each sample and observe the subsequent effects.
e. In the contact angle test, use a dedicated machine to reduce human mistake. If contact angle machines are not available, the testing process must strictly adhere to the standards used.

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