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ENHANCING PAPER'S BARRIER PROPERTIES FOR SUSTAINABLE PLASTIC ALTERNATIVES


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Abstract:

Sustainable development is a global imperative, uniting UN members behind 17 shared goals. Yet, the escalating crisis of plastic pollution looms large, threatening not only climate action but also life below water and on land. Conventional plastics, inherently non-renewable and non-biodegradable, worsen the situation, particularly single-use plastics.

Replacing single-use plastics with renewable, biodegradable alternatives is crucial. Paper offers eco-friendly solutions, especially in food contact applications. However, conventional paper falls short compared to plastic in its barrier properties against water, oil, and grease—critical for food protection.

This article presents a solution to address the aforementioned issues by utilizing a functional coating formulation, specifically a non-fluorochemical water-based polymer grafted starch emulsion. By applying this emulsion onto the paper surface, it has been observed that the Cobb60 values of the base paper have significantly decreased from an initial measurement of over 18 grams per square meter (gsm) to less than 0.6 gsm. Additionally, the TAPPI kit number has shown a remarkable increase from 0 to an impressive 12. These results surpass the performance of conventional surface-sizing starch, as the emulsion effectively establishes a robust barrier against water and oil/grease substances.

Keywords: Starch, food contact paper, barrier properties, water resistance, oil and grease resistance, OGR

1. INTRODUCTION:

Ever since the inception of petroleum-based plastic in the 1930s and the consequent commercial-scale production in the 1950s, commodity plastics have seamlessly integrated into the everyday lives of human society owing to their versatility and functionality as polymeric materials [1]. It is worth noting that the majority of commodity plastics commonly used today are made from petroleum, such as polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyethylene terephthalate (PET), among others. The global production of petroleum-based plastics has been on a steady rise, increasing from about 2 million tons in 1950 to over 400 million tons in 2017. Notably, the largest industrial sector that uses single-use plastics for packaging accounts for 36% of the total consumption, leading to plastic pollution on a global scale due to their inherent non-renewability and non-biodegradability [2].

Single-use plastics are widely utilized for plastic packaging, such as grocery bags, food packaging, bottles, straws, containers, cups, and cutlery [2]. These groups present significant challenges for reuse and recycling due to difficulties in collection, cleaning, and supply chain management. Various countries, including India, have implemented bans on single-use plastics to varying degrees. National regulations in India prohibit non-compostable plastic bags with a thickness of less than 50 microns, while several states and cities have also enforced bans on plastic carrier bags and other plastic materials [2-4]. One potential solution to mitigate global plastic consumption is to substitute single-use plastics with eco-friendly alternatives that are cost-effective, practical, and easily accessible, such as bio-based materials and biodegradable plastics. In addition to typical biodegradable plastics, such as thermoplastic starch (TPS), polylactic acid (PLA), and polybutylene adipate co-terephthalate (PBAT), which are promising alternatives, paper is one of the most appropriate candidates for this purpose, particularly as a food contact material.

Cellulosic fiber-based materials, particularly those consisting of paper, are known to possess inherent characteristics such as a hydrophilic surface and internal porosity, which result in limitations when compared to plastic in their capacity to serve as barriers against water and oil/grease. In order to overcome this issue, treatments involving the use of internal sizing chemicals such as rosin, alkenyl succinic anhydride (ASA), and alkyl ketene dimers (AKD) are commonly utilized to decrease the surface energy of cellulosic fibers, thereby rendering the paper material more resistant to water intrusion [5]. However, it is worth mentioning that due to the lower surface tension of oil/grease typically present in food (30 mN/m) compared to water (72.8 mN/m), it is necessary to apply fluorochemicals (FC) in addition to prior internal sizing chemicals to further decrease the surface energy of cellulosic fibers and prevent wetting and penetration of oil/grease. It is important to take into consideration that FC, also known as forever chemicals, particularly perfluorooctanoic acid (PFOA) and perfluorooctyl sulfonate (PFOS), have been banned in European countries due to their high persistence and bioaccumulation ability, but are currently not regulated in India [6].

To address the aforementioned issues in a simultaneous manner, a treatment based on non-fluorine chemistry should be considered. This article outlines a solution focusing on a non-fluorochemical water-based polymer grafted starch emulsion. The emulsion can be employed in the papermaking process, either by applying it to the surface of the paper web or to the surface of the pulp mold, to enhance the barrier properties against water and oil/grease. The emulsion was designed in compliance with notable International and National industrial standards, such as the US FDA regulations [7, 8] and BfR recommendations [9]. The application of this emulsion on paper surface is considered an effective practice to transform conventional paper into a food-contact barrier material, which may replace single-use plastics. In the following sections, we will discuss the practical application of the emulsion in both lab-scale settings and home compostability evaluation.

2. Materials and Methods

2.1 Materials

In this study, three types of base paper were obtained from different sources. Glassine paper was purchased from Siam Modern Enterprise Co., Ltd. (Thailand), kraft liner was purchased from Hong Thai Packaging Co., Ltd. (Thailand), and solid bleached board was kindly provided by SCG Packaging PLC (Thailand). The basic properties of base papers are listed in Table 1. Surface sizing chemicals, i.e. non-fluorochemical water-based polymer grafted starch emulsion and an oxidized starch, were provided by Siam Modified Starch Co., Ltd. (Thailand). The novel coating materials are made from a modified cassava starch grafted with a biodegradable polymer. A commercially available PE laminated paper for food contact application was purchased from a local supermarket.

Table 1 Comparison of the properties of the base papers.

Base Paper	Glassine		Kraft liner		Solid bleached board	
	Uncoated	Coated	Uncoated	Coated	Uncoated	Coated
Basis weight (gsm)	34.84 ± 0.93	39.59 ± 0.05	69.49 ± 0.28	79.35 ± 0.57	256.48 ± 1.91	271.13 ± 1.18
Coated weight (gsm)	-	5.78 ± 0.16	-	10.29 ± 0.36	-	15.75 ± 0.39
Thickness (µm)	45	45	100	110	400	410
Bulk (cm^3/g)	1.29	1.14	1.44	1.39	1.56	1.51
Density (kg/cm^3)	774.22	879.78	694.90	721.36	641.20	661.29
Smoothness (mL/min)	164	140	1,060	860	1,030	990
Porosity (mL/min)	47	5	560	5	400	20

2.2 Methods

2.2.1 Coating process

The coating process was performed using a K control coater (202, RK Print Coat Instruments, Litlington, Royston Hertfordshire, the UK). To enhance the surface properties of base papers, surface sizing was carried out using the emulsion described in Material section. The coating weight of the emulsion was varied depending on the type of paper, with a range of 5.0 to 16.0 grams per square meter (gsm). The coating speed was set to 135 mm/s, referred to as speed No.7. Following the coating application, coated paper samples were dried in an oven at a temperature of 100^0C for a duration of 3 minutes. Subsequently, the properties of coated papers were determined. Surface sizing using solution of gelatinized oxidized starch was separately applied to all base papers in a conventional manner to be used as comparative samples.

2.2.2 Measurement of the Cobb60 value

To measure the Cobb value of papers, the measurements were carried out at a temperature of 27 °C ± 1 and relative humidity (RH) of 65% ± 2, following the TAPPI standard T 441 om-09. At least three measurements were performed for each paper, and the average value was calculated and reported.

2.2.3 Measurement of oil and grease resistance

Oil and grease resistance of papers was performed following the TAPPI standard T 559 cm-02. For each paper, at least three measurements were performed. The average value was determined and reported.

2.2.4 Measurement of home compostability

Home compostability of coated papers was performed using an in-house method. A commercially available PE laminated paper was included in this experiment as a negative control. For each sample, a specimen measuring 15 x 20 cm^2 was prepared. The sample was placed in a controlled composting environment, simulating a home composting system. The composting process was monitored until the coated paper samples were completely composted.

3. Results and Discussion

3.1 Comparison of base paper properties

The different types of base paper exhibited variations in several properties (Table 1), including basis weight, thickness, bulk, density, smoothness, and porosity. Upon application of the emulsion coating, significant differences in liquid absorptive characteristics were observed. Uncoated base paper displayed poor water resistance due to its hydrophilic and porous nature [10], making it susceptible to absorption and penetration of the emulsion. The Cobb60 testing results (Figure 1) validated the distinct liquid absorptive performance of the base paper. These differences in absorptive properties can result in varying levels of absorption and penetration of the emulsion into the different base papers resulting in a substantial difference in coating weight from 5.78 gsm (glassine paper) to 15.75 gsm (solid bleached board). Upon the application of the emulsion, the porosity of papers was significantly decreased (Table 1). It indicated that the coated paper provided better coverage and excellent continuous film formation on the paper surface when compared with uncoated paper [11].

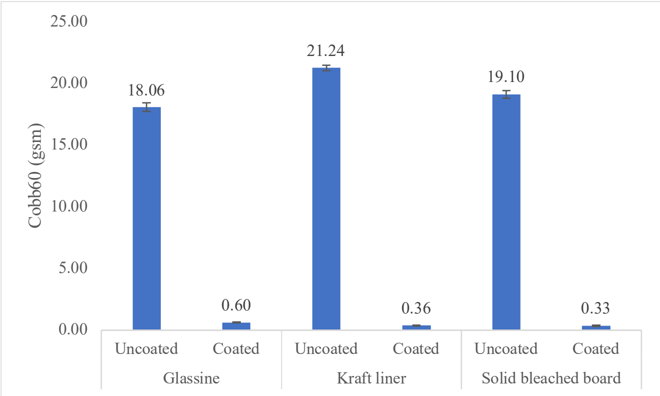

Figure 1 Cobb60 value of uncoated paper and coated paper with the emulsion.

3.2 Barrier performance of coated paper

3.2.1 Water resistance of coated paper

The Cobb value was a measurement of water absorption by paper over a specific period, typically expressed in grams of water absorbed per square meter. In this study, a Cobb60 value referred to the amount of water absorbed by the paper during a 60-second test. Figure 1 showed that Cobb60 values of coated papers were significantly lower than base paper. This indicated that, coated papers exhibited better water resistance compared to uncoated base paper. The improvement in water resistance could be attributed to the presence of the emulsion coating layers on paper. These coating layers effectively reduced both the number and size of pores on the paper surface. By decreasing the porosity, coating layers limited the penetration of water into the paper, resulting in a lower Cobb value. Despite conventional surface sizing using oxidized starch moderately reduced porosity of base paper, insignificant changes of Cobb60 values of the paper were observed (data not shown).

3.2.2 Oil and grease resistance of coated paper

Oil and grease resistance is an important factor that influences the barrier performance of packaging paper, particularly in the packaging of oily foods [12]. This parameter was performed following the TAPPI standard T 559 cm-02 (Figure 2), which utilized a kit value ranging from 0 to 12 to grade the paper's repellency to grease and oil. A higher kit value indicated a higher level of grease resistance in the paper. The results demonstrated that base paper exhibited a kit value of 0, indicating a lack of grease resistance. However, all coated papers achieved a kit value of 12, indicating a remarkable enhancement in grease resistance. This significant improvement in grease resistance could be attributed to the sealing of pores on paper surfaces, which prevented the penetration of oil and grease. The application of emulsion further contributed to the superior resistance against oil and grease by forming a continuous film on paper surfaces that exhibited high oil and grease resistance. While application of surface sizing starch on paper surface failed to exhibit the oil and grease barrier with the kit value of 0 (data not shown).

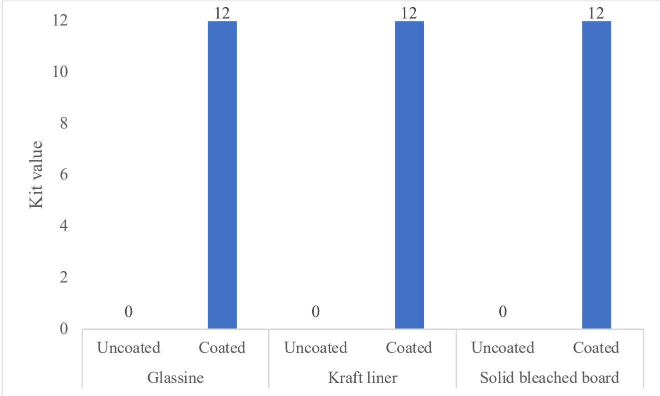

Figure 2 Kit value of uncoated paper and coated paper with the emulsion in oil and grease resistance testing.

3.3 Home compostable of coated paper

Home compostability referred to the ability of a material to undergo decomposition in a home composting environment. In the case of this emulsion, its eco-friendly characteristics made it a valuable alternative to plastic coatings in food packaging. Thus, a solid bleached board was selected as a material to investigate its home compostability when coated with the emulsion at a coating weight of 15.75 ± 0.39 gsm. One significant advantage of the emulsion was its ability to achieve home compostability within a relatively short time of 60 days (Figure 3), especially when compared to traditional plastic laminating materials for food packaging such as polyethylene (PE) laminated paper at approximately coating weight of 18.0 gsm. When this material ended up in a home composting system, it could take a significantly longer time to break down due to the composition of materials. The plastic product was known for its resistance to natural degradation processes. As a result, it could persist in the environment for many years contributing to plastic waste accumulation. Home compostability of the emulsion-coated papers within 60 days offered an attractive solution for sustainable food packaging. It allowed for efficient waste management and promoted the use of environmentally friendly materials, furthering the goal of reducing plastic usage and its associated environmental impact.

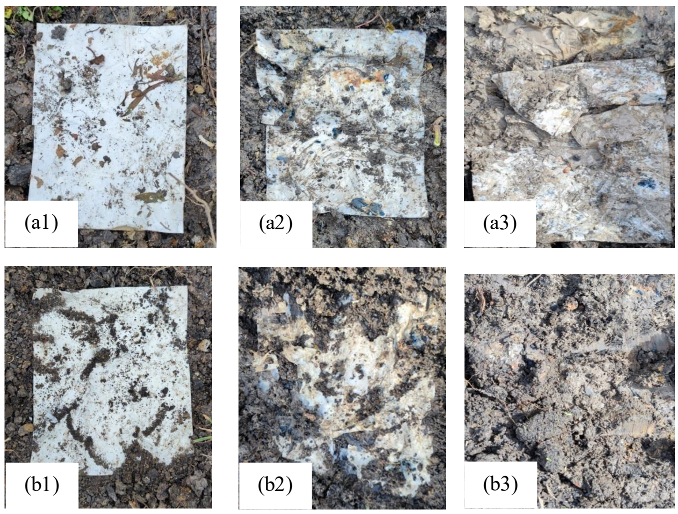

Figure 3 In-house testing for the home compostable of papers (a1) PE-laminated 0 day (a2) PE-laminated 30 days (a3) PE-laminated 60 days (b1) emulsion-coated 0 day (b2) emulsion-coated 30 days (b3) emulsion-coated 60 days

It is important to note that in addition to the barrier properties and its eco-friendliness of the emulsion coated paper, the emulsion also offers another desirable characteristic, i.e., online machinability. The application of the emulsion can be carried out using the conventional online surface sizing unit operation in a paper machine with minimal process adjustments. In spite of previously mentioned characteristics provided by the emulsion, other functional characteristics for food contact application should be also considered. These characteristics include water vapor transmission rate (WVTR), oxygen transmission rate (OTR), heat sealability, hot melt glue ability, recyclability, and repulpability. The testing of the emulsion coated paper following these parameters is currently underway. This information will be valuable for end users seeking to transition from PE lamination to this alternative solution.

4. Conclusion

Non-fluorochemical water-based polymer grafted starch emulsion exhibits the ability to be applied onto paper surfaces, effectively altering their surface properties to enhance hydrophobicity and reduce porosity. This transformation results in the development of paper with high barrier characteristics, as determined through standard testing methods, which is particularly advantageous for applications involving food contact. Additionally, the emulsion coated paper has demonstrated its capacity to undergo home composting, as evidenced by thorough in-house compostability assessments. This emulsion not only provides a straightforward means for paper manufacturers to attain water and oil/grease barrier properties but also serves as an environmentally-friendly solution for society, serving as an effective alternative to single-use plastics in the context of food contact.

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