

Polytetrafluoroethylene (PTFE) vs. PTFE-Free Coatings on Paper Label: Analysis of Label Mechanical and Performance Properties

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Abstract

Post-printed water-based (WB) coatings, commonly known as aqueous coatings, have gained popularity for paper-based label manufacturing because of their environmentally friendly characteristics. Polytetrafluoroethylene (PTFE) is one of the common additives added to the WB coatings to achieve heat resistance and rub resistance properties for the final product. PTFE is a synthetic fluoropolymer of tetrafluoroethylene, and is a category of Polyfluorinated Substances (PFAS). As of January 2024, the sale of food packaging containing PFAS is prohibited in the state of Minnesota, with expectations that this regulation will extend to other states because of the proven harm of PFAS to both humans and animals. PTFE-free WB coatings are emerging as an alternative; thus prompting the need to assess their performance. This research investigates whether PTFE-free WB coating can match the performance of PTFE WB coating for food packaging. The discussion focuses on comparing the impact of these coatings on mechanical properties and label performance of paper labels to inform potential future adopters of PTFE-free aqueous coatings for paper-based label application of mechanical properties and label performance factors as compared to aqueous coatings containing PTFE. The result shows that PTFE-free coating could be an acceptable alternative coating. With the exception of water-resistant properties, the tested PTFE-free coating equals or exceeds the PTFE coatings for rub, humidity, grease, heat, and pressure resistance abilities.

Paper serves as a frequently used substrate in the label printing industry. According to the Markets and Markets forecasting, paper and paperboard materials occupy one-third of the global packaging industry share (Trent, 2019; Tyagi et al., 2021). Paper

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and paperboard offer excellent characteristics for packaging applications, including stable mechanical properties, light weight, effective light barrier properties, ease of conversion and printing, recyclability, and utilization of renewable resources (Rhim & Kim, 2009). Because of papers' susceptibility to contamination and breakdown when exposed to water, oil, and heat, applying a post-printed aqueous coating is crucial to provide essential protection for paper-based labels (Tyagi et al., 2021). The label industry seeks materials that are less hazardous and more environmentally sustainable than incumbent products while maintaining important performance characteristics, including barrier properties. Stable water-based (WB) coatings can meet these requirements (Bakker et al., 2022).

Sixty to seventy percent of WB coatings are water; the remainder is comprised of solid materials. When the WB coating is applied to the substrate, the water component evaporates, and the solid particles form a water-insoluble film on the substrate. Acrylic resin, wax, surfactant, ammonia, and additives are basic components of the solid material in WB coatings. In addition, Polytetrafluoroethylene (PTFE) is frequently incorporated into WB coatings to enhance the product's heat and rub resistance. PTFE is a synthetic fluoropolymer derived from tetrafluoroethylene and falls under the fluoropolymer category of Polyfluorinated Substances (PFAS) (Lohmann et al., 2020). PFAS is commonly used in food packaging due to its hydrophobic and lipophobic properties.

One concern with using PFAS is its link to health problems. According to epidemiological studies, exposure to long-chain PFAS-contained products can contribute to kidney and testicular cancer, low birth weight, thyroid disease, decreased sperm quality, pregnancy-induced hypertension, and immunotoxicity in children. Furthermore, toxicological investigations in animals have established connections between exposure to PFAS and changes in mammary gland development, reproductive and developmental toxicity, testicular cancer, obesity, and immune suppression (Schaidt et al., 2017). The SF 20 regulation, signed into law in June 2021 and active in January 2024 in Minnesota, prohibits the utilization of perfluoroalkyl and polyfluoroalkyl substances (PFAS) on food packaging labels (Tsang, 2021). Eleven states have implemented measures to gradually eliminate the use of PFAS in food packaging (Safer States, 2024). Because of the concern about the adverse health effects of PFAS, prominent coating manufacturers have developed PTFE-free WB coating as an alternative to reduce PFAS residue on the labels.

The purpose of this research is to evaluate and compare the PTFE-free and PTFE WB coating performance on paper labels. A thorough examination of existing literature yielded no documented studies that compare PTFE and PTFE-free WB coating; the present research will focus on the influence of PTFE-free and PTFE coating on label mechanical properties and label performance. Two paper stocks, denoted Paper A (60#) and Paper B (47#) were used as testing substrates. Papers A and B were printed and coated using a Heidelberg XL 106 Sheetfed Offset Press.

Testing included analyzing unprinted Papers A and B, and then again after the papers were printed and coated.

Unprinted papers were subject to paper characteristic tests, including thickness and basis weight measurement, to describe the basic structural properties of the paper. Printed and coated substrates were tested for mechanical properties and label performance. The mechanical properties of the papers were analyzed using tests focused on the label-finishing process, including coefficient of friction, dry and wet rub, and wet blocking. The coefficient of friction test determines the force to separate two sheets of label samples during finishing. Dry and wet rub tests measure the abrasion resistance of label coating. The wet blocking test measures the durability of label coating under high pressure and replicates the humidity present in a typical label finishing environment. To assess label performance, the printed and coated papers were tested for water absorptiveness, heat resistance, and grease resistance. These tests gauge the performance of the label coating under conditions involving high volumes of water and oil, as well as at elevated temperatures.

Materials and Methods

Table 1 summarizes the materials utilized. As indicated in Table 1, two paper stocks, referred to as Paper A (60#) and B (47#), were printed and coated in Heidelberg XL 106 Sheetfed Offset Press. The viscosity of PTFE-free and PTFE coating was recorded at 15-20 seconds. The coatings were applied via an anilox roll on the press on the coating unit; the parameters of the anilox roll were 60° angle, 6.5 BCM cell volume, and a 280 LPI line screen, with a hexagonal cell shape.

Paper		
Paper A: 60# coated one side	Paper B: 47# coated one side	
Water-based Coating		
PTFE Coating	PTFE-free Coating	
Printing Press		
Heidelberg XL 106 Sheetfed Offset Press including a sheeting unit (roll to sheet converter at the paper feed), multiple ink units, a coating unit, and a drying unit		
Coating Anilox Roll		
60° angle	6.5 BCM cell volume, hexagonal	280 LPI line screen

Table 1: Summary of Materials Utilized

Materials Characterization

The primary materials used in the study were paper and water-based coatings. As the properties of these are germane to describing them as materials, the characterization testing is presented, together with a discussion of methods.

Paper characterization

A small number of unprinted sheets for each paper were reserved for paper characterization testing. The unprinted paper samples were stored in a measurement lab for 48 hours before testing. The relative humidity of the testing lab is maintained at 40%-50%, and the room temperature is maintained at 73 °F.

Paper characterization of the unprinted sheets was measured for thickness using a process described in the Technical Association for Pulp and Paper Industry (TAPPI) / American National Standards Institute (ANSI) standard T411 om-21 (2021), and for basis weight in GSM using the process described in TAPPI / ANSI T410 om-19 (2019). The paper characterization results are shown in Table 2.

	Thickness	
	Paper A (60#)	Paper B (47#)
Mean	3.0	2.5
Standard Deviation	0.1	0.1
Basis Weight (GSM)		
Mean	8.9	70
Standard Deviation	0.20	0.25

Note. Results based on five number of individual readings

Table 2: Unprinted paper characterization

Water-based Coating Characterization

The water-based coatings were tested for viscosity. The viscosity was measured using a #3 Zahn cup at 77 °F. The results and coating ingredients are presented in Table 3.

As indicated in Table 3, water is the major composition of both the PTFE and PTFE-free coatings tested: water comprises 60% -70% of the coating material, with solid materials comprising 30-40% of the coating composition. Sodium Dioctyl Sulfosuccinate and

	PTFE	PTFE-free
Viscosity (Seconds)	15-20	12-20
Ingredients		
Water %	60 - 70	60 - 70
Solids %	30-40	30 -40
Sodium Dioctyl Sulfosuccinate %	< 4.0	< 4.0
Ammonium Hydroxide %	< 2.0	< 2.0

Table 3: Water-based coating characterization

Ammonium Hydroxide are the basic components of the solid materials in the coatings. The remaining ingredients are withheld by the coatings manufacturers.

Printing and Coating Process

The samples were printed and coated at Multi-Color Corporation, a label manufacturing company in Rochester, New York. The respective papers were fed into the press as a paper roll and then cut into sheets in the sheeting unit. Label images were printed on the sheets using oil-based offset lithographic printing inks by the inking units. Following the image printing, the respective coatings were applied on papers via an anilox roller in the coating unit. Finally, the samples were dried in the drying unit of the press. The heat capacity of the drying unit was set at 60%, and the end temperature of the paper was recorded at 95-100° F. Printed and coated samples of each paper were retained for subsequent testing.

Both the unprinted paper samples and printed and coated paper samples were stored in a measurement lab for 48 hours before testing (relative humidity 40-50% / 73°F).

Post-print and coating testing

The post-print testing is divided into two categories: label mechanical properties tests for the printed and coated paper, and label performance tests for the printed and coated paper. The label mechanical properties tests for printed and coated papers included the coefficient of friction, dry rub resistance, wet rub resistance, and wet blocking. The label performance tests included water resistance, grease resistance, and heat resistance. According to TAPPI T491 om-08, the water resistance of paper can be measured by water absorptiveness test described in TAPPI

T441 om-20. The wet blocking test was conducted with methods consistent with the ASTM D918-99, as follows:

- Two printed and coated samples were cut to 1.25 x 1.25 inches
- A pipette was used to place a single drop of water on one of the cut samples
- The two samples were placed face to face under 50 Psi pressure for 48 hours
- The samples were separated, and visually analyzed

The heat resistance test followed an internal procedure used by the printing facility, as follows:

- Two printed and coated samples were cut to 2 x 5 inches
- Two printed and coated samples were placed under two clamping jaws for ten seconds
- The label was heated up until 250 °F during these ten seconds
- The samples were separated, and visually analyzed

Label Mechanical Properties	
Test	Standard
Coefficient of friction (kinetic)	TAPP / ANSI T549 om-20
Dry rub resistance	TAPPI / ANSI T830 om-18
Wet rub resistance	TAPPI / ANSI T830 om-18
Web blocking	ASTM D918-99
Label Mechanical Tests	
Water Absorptiveness	TAPPI / ANSI T441 om-20
Grease Resistance	TAPPI / ANSI T559 cm-12
Heat resistance	Internal Printing Facility Guideline

Table 4: Post-print and coating tests and standards

The corresponding standards for the respective tests are shown in Table 4.

Results and Discussion

Results of the post-printed and coated labels begin with a presentation of the mechanical properties, followed by those tests that describe label performance factors.

Label Mechanical Property: Paper Coefficient of Friction Test

The coefficient of friction test results of Paper A and B printed and coated samples are shown in Table 5. The coefficient of friction as defined by TAPPI / ANSI T549 om-20 (2020) includes both static and kinetic friction testing. The kinetic friction value is of particular importance for label finishing; it refers to the ratio of the force needed to maintain consistent relative motion between surfaces to the normal force (Technical Association for the Pulp and Paper Industry / American National Standards Institute, 2009) Label manufacturing companies typically focus on

	Paper A		Paper B	
	PTFE	PTFE-free	PTFE	PTFE-free
Mean	0.2	0.2	0.2	0.2
Standard Division	0.0	0.0	0.0	0.0

Note. Results based on 5 number of individual readings

Table 5: Coefficient of Friction (kinetic) for post-printed and coated labels

kinetic friction rather than static friction. Therefore, only the kinetic values are discussed in the results.

As illustrated in Table 5, both papers A and B coated with PTFE-free and PTFE

coating show the same value of kinetic friction. This result indicates that PTFE-free coating will not change the intrinsic coefficient of friction value.

Label Mechanical Property: Dry and Wet Rub Resistance

Rub resistance is assessed by both a dry rub test and a wet rub test. The dry and wet rub test as defined by TAPPI / ANSI T830 om-18. Both tests conducted 1,600 rubs on the samples. For wet rub resistance test, a pipette was used to place two drops of



Paper A with PTFE Coating



Paper A with PTFE-Free Coating



Paper B with PTFE Coating



Paper B with PTFE-Free Coating

Figure 1: Dry Rub Resistance Test

water on the base sample before rubbing. As this test requires a visual analysis, the post-testing results are illustrated in Figures 1 and 2.

As shown in the dry rub test result in Figure 1, no noticeable ink was picked up, and no marks were visible on either Paper A or Paper B after dry rub testing. The results suggest that PTFE-free and PTFE coating provide satisfactory levels of dry rub resistance for the papers tested.

Turning to wet rub resistance is shown in Figure 2, a noticeable amount of ink was



Paper A with PTFE Coating



Paper A with PTFE-Free Coating



Paper B with PTFE Coating



Paper B with PTFE-Free Coating

Figure 2: Wet Rub Resistance Test

picked up in Papers A and B with both the PTFE-free and PTFE coating, although it is observed that Paper B exhibited better wet rub resistance than Paper A.

Label Mechanical Property: Wet Blocking Test

Blocking refers to the undesirable adhesion between two surfaces under pressure and temperature constraints. According to Skillington (2010), “The occurrence of blocking between two coated paper surfaces in contact with each other can be influenced by factors such as temperature, pressure, surface roughness, and surface energy” (p. 29). Block testing assesses the coating’s ability to protect substrate and



Paper A with PTFE Coating



Paper A with PTFE-Free Coating



Paper B with PTFE Coating



Paper B with PTFE-Free Coating

Figure 3: Wet Blocking Test

ink under the application of pressure and in elevated humidity conditions. Figure 3 illustrates the results.

A visual analysis of the wet blocking test indicates no noticeable ink pickup with Paper A for either the PTFE-free or PTFE coated papers. For Paper B, there is a discernable ink pick-up area in both the PTFE-free and PTFE-coating samples. The ink pick-up area of the PTFE-free coating appears to be less than the PTFE coating.

Test for Label Performance Properties: Water Resistance

The water absorptiveness test, conducted in accordance with the TAPPI/ANSI T441 om-20 instructions, provides data used for analyzing the water resistance

	Paper A		Paper B	
	PTFE	PTFE-free	PTFE	PTFE-free
Mean	31	035	6	6
Standard Division	3.1	1.5	0.6	2.1

Note. Results based on 5 number of individual readings

Table 6: Water Absorptiveness Test: Weight of Water Grams per Square Meter

of the printed and coated samples. The results of the water absorptiveness test of printed and unprinted Paper A and B samples are shown in Table 6.

According to the water absorptiveness test definition, the test result indicates the amount of water absorbed in a limited time frame by one square meter of a testing substrate (Technical Association for the Pulp and Paper Industry / American National Standards Institute, 2020).

A lower value of the water absorption suggests that the coating could better prevent

water penetration. For Paper A, the water absorption value of PTFE coating is lower than that of PTFE-free coating. For Paper B, PTFE-free coating has the same test value as PTFE coating. There is more variance in water absorption values with the PTFE coating than the PTFE-free coating for Paper A; the opposite was observed with Paper B.

Test for Label Performance Properties: Grease Resistance

Like the rub resistance and wet blocking tests, the grease resistance test relies on a visual analysis. The grease resistance test follows the TAPPI /ANSI T559 cm-12 standard instructions.



Paper A with PTFE Coating



Paper A with PTFE-Free Coating



Paper B with PTFE Coating



Paper B with PTFE-Free Coating

Figure 4: Grease resistance test

Visual results of the grease resistance test for of printed and coated paper A and B samples are shown in Figure 4.

In the case of Paper A, neither PTFE nor PTFE-free coatings exhibited noticeable ink pickup after the test solution was wiped off within fifteen seconds. This contrasts with the results for Paper B, where most of the ink was picked up by the testing solution.

Test for Label Performance Properties: Heat Resistance

The heat resistance test follows the internal printing facility guideline instructions.



Paper A with PTFE Coating



Paper A with PTFE-Free Coating



Paper B with PTFE Coating



Paper B with PTFE-Free Coating

Figure 5: Heat resistance test

Visual results of the heat resistance test for of printed and coated paper A and B samples are shown in Figure 5.

As shown in Figure 5, there are marks due to ink pick on both the PTFE-free and PTFE coatings on Paper A. That demonstrates that PTFE-free and PTFE coating was melting during the heating therefore the ink has been picked up to the top sample. For Paper B, the observed ink pick-up on PTFE coated sample after heating was more subtle. Yet, the PTFE-free coated samples demonstrated no observable ink pick up after heating.

Conclusions

The test results for label mechanical properties and label performance tests were utilized to analyze the performance of PTFE and PTFE-free coatings on paper labels. In the mechanical properties test, the Coefficient of Friction (kinetic) value was found to be identical for both PTFE and PTFE-free coatings. For the dry and wet resistance tests, as well as the wet blocking test, the PTFE-free coating exhibited equivalent performance to the PTFE coating. Notably, the PTFE-free coating demonstrated superior protection for Paper B in the wet blocking test. In the label performance test, the PTFE-free coating displayed comparable performance to the PTFE coating in grease resistance and heat resistance tests, with even better heat-resistant protection observed for Paper B. In the water absorptiveness test, the PTFE-free coating demonstrated equivalent performance to the PTFE coating for Paper B, while Paper A with the PTFE coating exhibited a slightly better water-resistant ability than paper with PTFE-free coating. The variance between the

coatings exhibited by the water absorptiveness test results for Paper A and Paper B was especially curious: the variance was greater with Paper A water absorptivity with the PTFE coating, and with Paper B the variance was greater with the PTFE-free coating. This suggests that there are properties in the papers themselves that may influence the results, underscoring the need for future researchers to examine a wider array of papers in similar test procedures. Practitioners should also examine the results to the practical requirements to ascertain the potential practical implications of these findings.

In summary, the test results suggest that for label mechanical properties and performance tests, the PTFE-free coating serves as an acceptable alternative to PTFE coating, as evidenced by similar rub, humidity, grease, heat, and pressure-resistant abilities. In some instances, notably the heat resistance and wet blocking performance, the PTFE-free coating outperformed the PTFE coating on Paper B. Despite consistent testing protocols for Paper A and Paper B, discrepancies in results were observed. These can be likely attributed to inherent differences in the paper properties of the two substrates. To obtain a comprehensive understanding of PTFE-free coating properties, it is suggested that future research expands on the testing here to include various paper stocks to better inform the discussion. Further, future researchers could examine different formulations of PTFE and PTFE-free coatings.

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