Adhesion with purpose: The value of primers in sustainable flexible packaging

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ABSTRACT: Primers play a crucial role in flexible packaging by providing adhesion, enhancing performance, and improving the overall quality of packaging structures. As the packaging industry shifts towards more sustainable solutions, it brings new challenges for meeting adhesion requirements. Different types of sustainable materials, with their complicated physical and chemical properties, usually result in poor adhesion in extrusion coating or extrusion lamination, whether this is due to fast crystallization, secondary crystallization, low processing temperature, lack of functional groups, or a combination thereof. Water-based primers ensure that these innovations meet both functional and environmental standards for the packaging of tomorrow. Conventional water-based primers, including polyethyleneimine (PEI) and ethylene acrylic acid (EAA), offer significant advantages in sustainable packaging design by chemically modifying the surface of the substrate to enhance adhesion.

In this study, we will discuss adhesion issues in three case studies involving sustainable packaging materials: (1) extrusion coating of polyvinyl alcohol (PVOH) on paper; (2) extrusion lamination of paper and metallized film with starch biopolymer; and (3) extrusion coating of polyhydroxyalkanoates (PHA) on paper. These cases represent three adhesion challenges related to sustainable materials, namely fast crystallization rate, low processing temperature, and secondary crystallization. A three-step adhesion improvement procedure was employed to identify the proper primer in each case study. This procedure included a wetting-out test with primer, an adhesion test, and an extrusion test with priming.

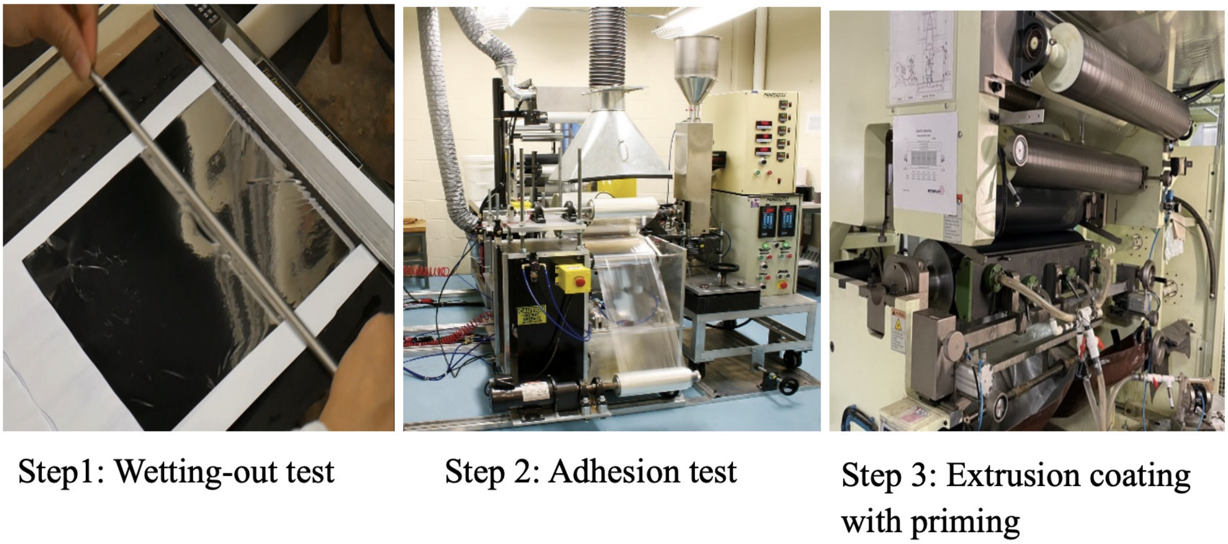
In our results, strong fiber tearing or destructive bonds were achieved in each case with the help of water-based primers. These results demonstrate the value of water-based primers in enabling the transition to more sustainable packaging structures without compromising performance.

Application: One of the most common issues associated with using biodegradable materials in flexible packaging is poor adhesion between the biodegradable and other parts of the structure. This paper focuses on solutions based on water-based primers to address adhesion issues caused by factors such as fast crystallization, secondary crystallization, and low processing temperature that are normally associated with biodegradable materials. Readers from the packaging industry who practice with biodegradable materials and experience similar issues can implement these findings into their product development.

As the packaging industry shifts towards more sustainable solutions, companies have taken steps to replace traditional plastic packaging with biodegradable alternatives to reduce end-of-life impact. In recent years, we have witnessed a rapid rise in the testing, evaluation, and implementation of new packaging materials that are chemically different from the traditional petroleum-based plastics. Examples of these materials include polylactic acid (PLA), polybutylene adipate terephthalate (PBAT), polybutylene succinate (PBS), polyhydroxyalkanoate (PHA), starch, and extrudable polyvinyl alcohol (PVOH) [1-4]. These materials are biodegradable under proper conditions, and some are also compatible with paper recycling processes. Packaging constructed with these types of materials can disintegrate into molecules within a relatively short period of time by naturally occurring processes or be safely put into a paper recycling stream.

Although biodegradable resins offer apparent sustainability advantages compared to traditional plastic packaging materials, they also introduce new challenges in handling and processing. Biodegradable resins are usually sensitive to moisture and temperature and exhibit vastly different rheological and chemical properties from traditional resins, such as low-density polyethylene (LDPE). Consequently, applications of these resins would require not only different processing methods to achieve optimal output and line speed, but also novel approaches to obtain good adhesion to fulfill the desired performance. A straightforward solution is to use water-based primers when processing biodegradable resins.

Since it was invented, water-based primer for improving adhesion between dissimilar packaging materials has become an integral step in the extrusion coating process [5]. Applying primer helps extrudates spread uniformly by creating high surface tension and lowering contaminants on the substrate [6]. Additionally, primer combines the extru-



1. Three-step adhesion improvement procedure using water-based primer, solving adhesion issues.

date and substrates via various chemical and physical bonds [7]. The ultimate performance of primer depends on several factors, including the surface properties of the substrate; pretreatment level; chemistry of the primer and its coat weight; primer drying temperature; chemistry and extrusion temperature of the extrudate; extrusion process equipment configurations; and contaminates from various sources. If offline priming is needed, additional factors such as winding tension and moisture level (which are related to blocking), product inventory holding time, and backside contamination must also be considered.

Biodegradables differ from conventional extrusion coating resins like LDPE in how these factors affect adhesion because of their various physicochemical properties. Despite our understanding and practical experiences in adhesion improvement with conventional packaging materials, the application of water-based primer in biodegradable materials is still a relatively unexplored area. Literature in this field is scarce [8,9]. Useful data is usually unavailable in public. This research paper compiles some results from studies focused on solving adhesion issues with extrusion coating of PVOH, starch polymer, and PHA on paper or film. The goal is to elucidate various adhesion issues associated with different biodegradable polymers and demonstrate how to select and implement a water-based primer to solve these issues

A three-step adhesion improvement procedure has been developed and applied to solve the industry's toughest adhesion issues with water-based primers. It consists of the following steps: (1) wetting-out test, (2) adhesion test, and (3) extrusion with priming. The procedure is shown in **Fig. 1**. In this paper, we will show results from three individual studies using this methodology to solve adhesion issues of biodegradable resins.

1. *Case Study 1* involves extrusion coating of PVOH on paper. Extrudable PVOH usually has very low adhesion to paper due to its fast crystallization. This case demonstrates how to use water-based primer with special processing parameters to obtain good adhesion. Part of the results of this study have been published in [8].
2. *Case Study 2* involves extrusion coating starch polymer on metallized film. Starch polymers usually have very poor adhesion to films due to their high polarity, low process temperature, and lack of anchor points on the films. The results of this study show how primer improves the compatibility between starch and metallized film. It also demonstrates how performance varies depending on the specific substrate of the metallized film.
3. *Case Study 3* is related to extrusion coating PHA on paper. Due to its chemical similarity to polyester, PHA exhibits comparable adhesion characteristics. However, under some circumstances, the adhesion of PHA to paper can decay from very good green bonds to no adhesion over a few days. This study demonstrates how using a water-based primer can help overcome this intrinsic issue with PHA and bring lasting bonds to the structure for the lifetime of the package.

With good adhesion and other desired properties, paper or films coated with these biodegradable materials can be used in some common types of packaging. For example, paper coated with PVOH or starch polymer and lined with a plastic film or moisture barrier coating can have excellent gas, oil, and grease resistance, as well as good moisture resistance. They can be used in packaging of non-food such as paper mailers and shipping bags, as well as food packaging including chip and snack bags; satchels for nuts, fruits, and other confectionaries; and pouches for oatmeal, coffee., and similar items [9,10]. On the other hand, paperboard coated with PHA has excellent water and heat resistance and can be used for holding hot and cold beverages. From a sustainability perspective, the structures based on these materials are biodegradable and compatible with the paper recycling processes.

METHODS AND MATERIALS

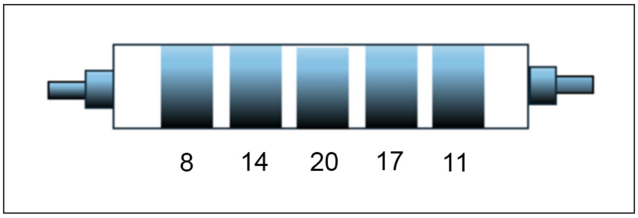
This paper is based on three independent studies conducted at Mica Corporation (Shelton, CT, USA) and in collaboration with Mica's partners. The three studies are:

1. Extrusion coating of PVOH on paper.
2. Lamination of metallized film and paper with extruded starch polymer.
3. Extrusion coating of PHA on paper.

Case Study 1

The first study — extrusion coating of PVOH on paper — involved screening many water-based primers. The wetting out test was carried out on a 68 g/m^2 (42 lb/ream) kraft paper. Eight primers were evaluated in this step: two polyethyleneimine (PEI)-based primers (solids: 5% and 12%); an ethylene acrylic acid (EAA)-based primer (solids: 10%); a vinyl acetate ethylene (VAE)-based primer (solids: 50%); a polyurethane (PU)-based primer (solids: 30%); a polyolefin (PO)-based primer (solids: 40%); a PVOH-based primer (solids: 8%); and an acrylate polymer (AP)-based primer (solids: 40%). The paper was corona treated and then coated with individual primers by hand drawdown starting at the lowest possible coat weight and progressively increasing the coat weight. Uniformity of the coating and defects, such as voids, blisters, and fisheyes, were checked visually.

The adhesion test was carried out with samples prepared by a laboratory-scale Randcastle extrusion coater (Randcastle Extrusion Systems; Cedar Grove, NJ, USA) that consists of three heated and cooled barrel zones and a 1-in. general purpose screw with length-to-diameter (L/D) ratio of 24 through a 25-cm-width slot die. The PVOH resin used in the test had a density of 1.15–1.25 g/cm^3, MFR of 10.0–14.5 g/10 min, and melting temperature of 170°C–180°C. The paper sheets coated with individual primers, plus a control of no primer, were fed into the laboratory coater. The PVOH was extruded at 210°C onto the primed paper. The revolutions per minute of the extruder (35 rpm) and line speed (10 m/min) provided ~25 µm coating thickness. The adhesion level (fiber tearing) between the PVOH coating and paper was checked immediately after coating and again 24 h later. We used four categorical scales to measure the level of fiber tearing and assigned a value to each level: (1) Level 1: no fiber attached to the coating (0%); (2) Level 2: some fiber attached to the coating (10%); (3) Level 3: fiber covering the coating unevenly (50%); and (4) Level-4: thick and even fiber fully covering the coating (100%). Each sample was measured three times, and the average was reported.



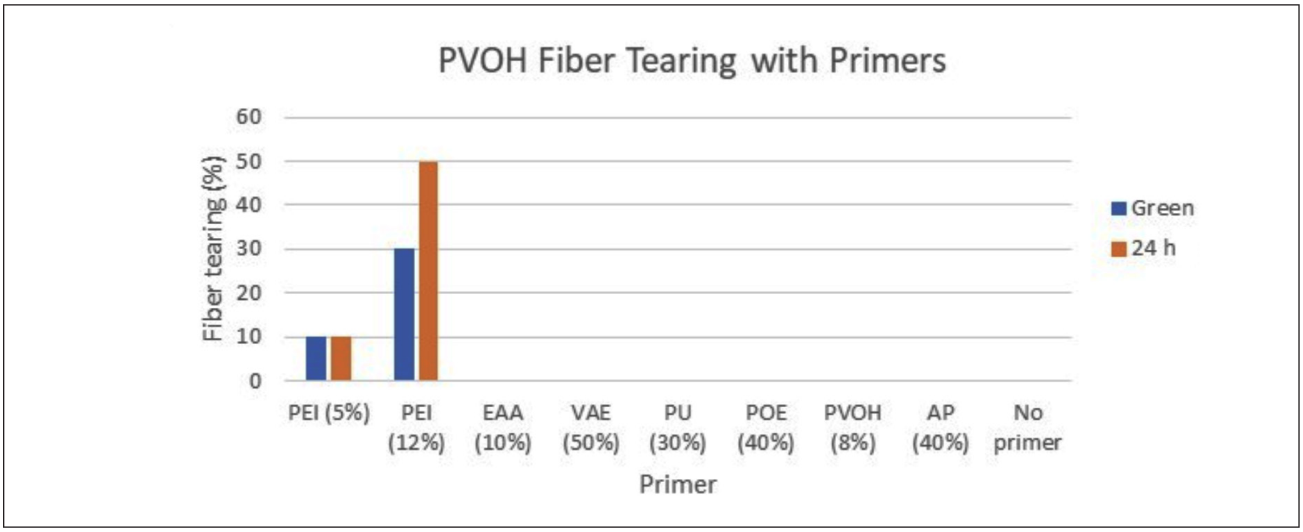
2. Schematic drawing of banded gravure cylinder used in the extrusion coating.

In the third step, primers determined from the first and second step were further evaluated on a pilot scale extrusion coating line at Optex Process Solutions in Phoenix, NY, USA. This extrusion coating line consists of three extruders that are 2.5 in., 2 in., and 1.25 in. in diameter, with each at 34:1 L/D and connected to a five-layer vane adjustable feedblock and a 40-in. Nordson EDI EPC internally deckled die (Nordson; Westlake, OH, USA). The priming station runs with a direct gravure applicator, a chambered doctor blade with a circulation pump, and a two-zone heated air drier. The gravure cylinder is a banded cylinder (**Fig. 2**) comprising five bands of different coating volumes: 8, 14, 20, 17, and 11 billion cubic microns (BCM). This type of special gravure cylinder allows for various coating weight applications at the same time across a web width.

The same PVOH resin from Step 2 was extruded at a temperature of 221°C. The extrusion was carried out at line speeds from 61 m/min to 183 m/min. At 61 m/min and 91 m/min, the extruder speed was adjusted proportionally with the line speed to keep the coating thickness relatively constant (~25 µm). For 91 m/min and above, the extruder speed was held constant, and the thickness diminished proportionally to line speed, namely ~19 µm at 122 m/min; ~17 µm at 152 m/min; and ~13 µm at 183 m/min. The finished paper and PVOH laminates were checked for fiber tearing and adhesion strength, which was measured by peel test with a tensile tester.

Case Study 2

The second study — lamination of metallized film and paper with extruded starch polymer — employed the same three-step procedure to identify a primer, with the exception that the laboratory extruder was replaced with a film laminator to prepare samples for adhesion testing due to processing issues. The current screw design was insufficient to process the starch polymer. The wetting-out test was carried out with five primers on three types of metallized films: a metallized biofilm; a metallized biaxially oriented polypropylene (BOPP) film; and a metallized PE film. The five primers included two different ethylene acrylic acid (EAA)-based primers (solids: 5% and 10%); a polyurethane (PU)-based primer (solids: 40%); a PVOH-based primer (solids: 8%); and a PEI primer (solids: 12%).



3. Fiber tearing in paper by polyvinyl alcohol (PVOH) for different primers (PEI: polyethyleneimine; EAA: ethylene acrylic acid; VAE: vinyl acetate ethylene; PU: polyurethane; POE: polyolefin elastomer; AP: acrylate polymer).

The adhesion test was carried out with samples prepared by a GBC Heatseal H600 Pro (GBC; Lake Zurich, IL, USA) at 96°C, 3-s dwell, and 40 psi. The films coated with individual primers were laminated with the starch polymer that was coated on a paper. In addition to five primers, a control of no primer was added to the list. The starch polymer has a density between 1.35 and 1.43 g/cm^3 and glass transition temperature (T_g) between 40°C–80°C. Green bond and bond strength after a week were measured by peel test with a tensile tester.

The extrusion coating evaluation was conducted on the same pilot scale extrusion coating line with the same banded gravure cylinder for priming as in the first study. The starch polymer was extruded onto three metallized films at 100°C and a line speed of 61 m/min. The coating thickness of the starch was ~25 µm. An uncoated paper was laminated to the metallized films via the extrudate to form the film, starch polymer, and paper composite structure. The bond strength between metallized film and starch was examined after the extrusion.

Case Study 3

The third study — extrusion coating of PHA on paper — involved only two primers: a proprietary primer (solids: 50%), and a biodegradable primer (solids: 30%). The wetting-out test was performed on a substrate that is a typical paperboard used to make paper cups. Because of lack of the PHA resin or film thereof, the adhesion test was skipped in this study. The primers were then directly evaluated on the pilot scale extrusion coating line. A typical density for PHA is 1.25–1.35 g/cm^3, with a melting point between 160°C–180°C. The PHA resin was extruded at 170°C with a line speed of 55 m/min. The bond strength between paper and the PHA resins was tested immediately after production and then at lapses of 3 days, 13 days, and 10 months.

RESULTS AND DISCUSSION

Case Study 1

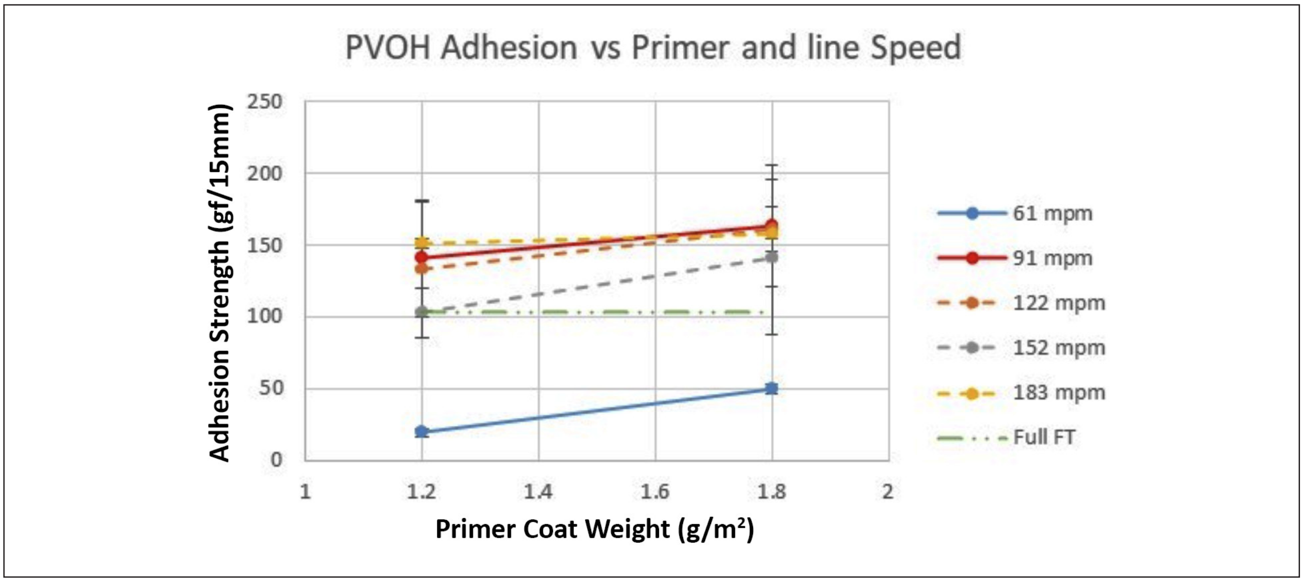
The first step of Case Study 1 was to examine the wetting-out of eight primers on a kraft paper. All of the primers showed good compatibility with the paper. Therefore, they all proceeded to the adhesion test.

The adhesion test measured the level of fiber tearing of each primer, whose values are shown in **Fig. 3**. Their related coat weights are shown in **Table I**.

It is clear from the results that only PEI-based primers can generate fiber tearing between PVOH resin and paper. Among them, PEI (12%), which has more than twice the solids of PEI (5%), showed the highest fiber tearing. Additionally, the extent of fiber tearing increased over 24 h for PEI (12%). The high efficacy of the PEI primer can be at-

	PEI (5%)	PEI (12%)	EAA (10%)	VAE (50%)	PU (30%)	POE (40%)	PVOH (8%)	AP (40%)	No Primer
Coat weight, g/m^2	2.6	3.0	1.6	6.7	4.6	5.4	1.2	1.6	0
PEI: polyethyleneimine; EAA: ethylene acrylic acid; VAE: vinyl acetate ethylene; PU: polyurethane; POE: polyolefin elastomer; PVOH: polyvinyl alcohol; AP: acrylate polymer.									

I. Estimated coat weights of primers in the adhesion test of PVOH (Study 1).



4. Comparing PVOH to paper adhesion with varied primer coat weight and line speed. Green dashed and dotted line corresponds to the estimated fiber tearing seal strength.

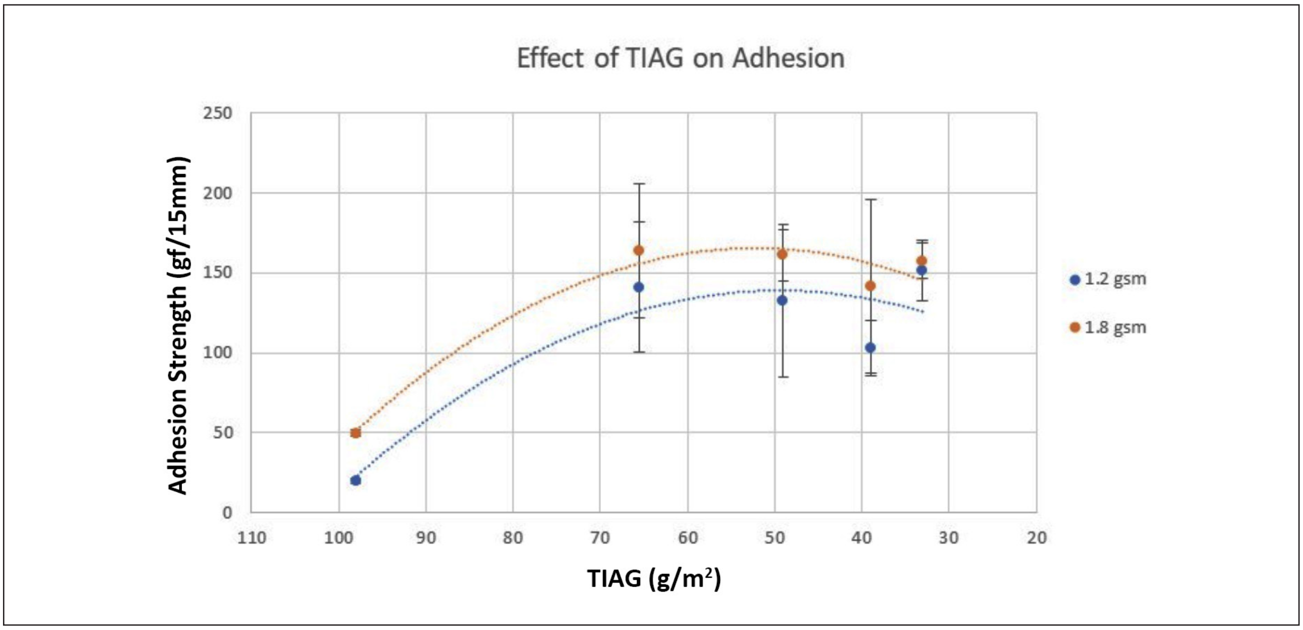
tributed to its physical and chemical structures. Compared with other polymers, such as ethylene acrylic acid, polyurethane, and acrylate polymer, branched PEI has very low crystallinity and high potency to form hydrogen bonds with PVOH. Also, the tendency to form bonds increases with the concentration of PEI, given the fact that PEI (12%) has higher solids content than PEI (5%), but their coat weights were rather similar in the experiment. One possible explanation is that high solids content slowed the absorption of the primer into the paper and was thus more available to interact with PVOH. Additionally, PEI's highly branched structure, which has a very low crystallinity and high potency to interactions with PVOH via hydrogen bonding, may have slowed the crystallization of PVOH on paper. Choi, Hwang, and Lee studied the blending of PVOH, PEI, and graphene oxide and found that the T_g of the blend was significantly higher than each individual component [11]. Higher T_g usually leads to slow crystallization. Furthermore, Hamouda et al. studied the PVOH, polyethylene glycol (PEG), and PEI blend in gas membrane and discovered PVOH crystallization was partially inhibited by the interactions between the amorphous PVOH and PEI blend [12].

Figure 4 shows the results from the extrusion coating of PVOH on paper with PEI (12%) primer on the pilot line. **Table II** contains the information on estimated coat weights for the five bands on the rotary gravure cylinder that was used for priming in the extrusion coating trial. The results indicate that both primer and line speed are important parameters for obtaining full fiber tearing of paper. Adjusting PEI (12%) coat weight can increase the adhesion of PVOH to paper. For example, the bond was increased from 20 to 50 gf/15 mm by increasing primer coat weight from 1.2 g/m² to 1.8 g/m². But primer alone cannot achieve full fiber tearing without increasing line speed, which reduces the time in air gap (TIAG). After line speed was increased from 61 m/min to 91 m/min, full fiber tearing was achieved at both coat weights. On the other hand, even at high line speed, the effect of primer on adhesion is still apparent when comparing the bond strength at 1.2 g/m² and 1.8 g/m². The film thickness of coatings at 122 m/min, 152 m/min, and 183 m/min are gradually reduced as line speed increases. When comparing their adhesion levels, they are very similar within the experimental errors. This result further confirms the combined effects of primer and line speed on adhesion.

Figure 5 plots the adhesion of PVOH vs. TIAG or time in air gap. The TIAG is a function of extrusion speed, air gap, and line speed. In the graph, the value of TIAG is plotted in reverse order. It is clear from the plot that as TIAG decreases, adhesion increases for PVOH, which is very un-

Primer	8, BCM	14, BCM	20, BCM	17, BCM	11, BCM
PEI (12%, no dilution), g/m²	0.6–0.7	1.0–1.2	1.5–1.8	1.3–1.5	0.8–1.0
BCM: billion cubic microns; PEI: polyethyleneimine.					

II. Estimated coat weights of primer in the extrusion test of PVOH (Study 1) for each of the five bands on the rotary gravure cylinder that was used for priming in the trial.



5. Effect of time in air gap (TIAG) on adhesion of PVOH to paper.

like conventional LDPE. Foederer and Morris studied the effects of TIAG on cooling and re-solidification and the interaction between line speed and thickness [13]. Their study indicates that high extrusion speed, high line speed, and small airgap favor higher temperature at nip, which is important for PVOH to achieve good adhesion with paper.

Case Study 2

In Case Study 2, the wetting-out test involved five primers, which were applied on three metallized films at their lowest recommended coat weights. Without dilution, all primers showed no signs of incompatibility with the films. However, as the dilution increases from 1:1 to 1:3, incompatibility increases. Corona treatment of the films helps improve the compatibility between the metallized film and diluted primers.

In the adhesion test, the coat weight of each primer was kept at 0.2 g/m^2. The only exception was primer PU (30%), whose coat eight was at 0.4 g/m^2. This was because dilution can cause phase separation in PU (30%). The results are shown in **Fig. 6**, and their related coat weights are shown in **Table III**.

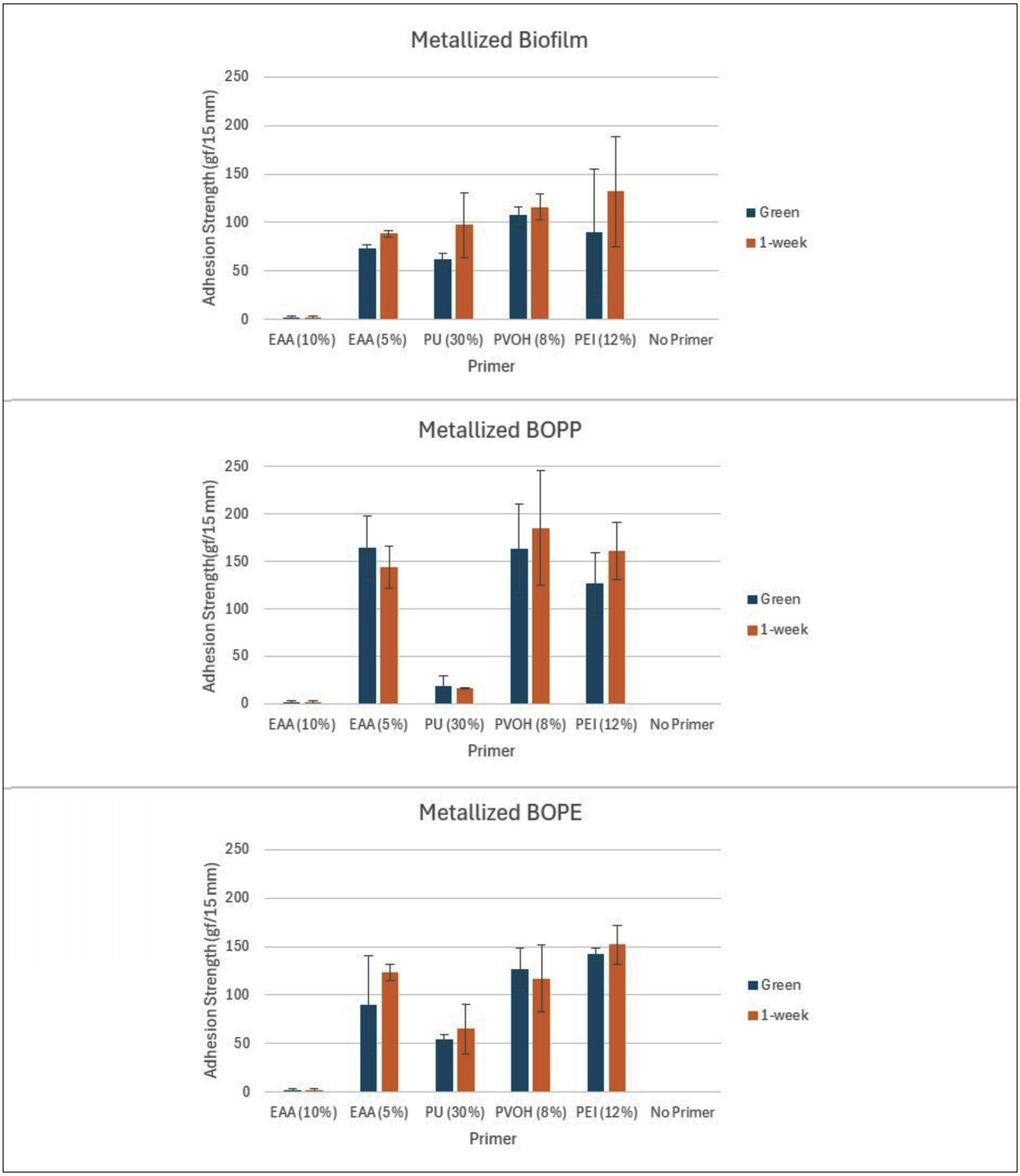
In Fig. 6, three individual plots correspond to three types of metallized films, namely, metallized biodegradable film, metallized BOPP film, and metallized biaxially oriented polyethylene (BOPE) film. Comparing five primers and the control across any of the plots, primers provide significant contribution to the adhesion of starch polymer to the film. Without primer, the failure is between the starch and metal layer, which has a very low adhesion strength. With primer, the failure is either between the metal layer and film or between the primer and metal layer, which also has much higher adhesion strength. The only exception is EAA (10%), where the failure is between the primer and starch. What is interesting is the difference between EAA (10%) and EAA (5%). The former is a widely used primer for aluminum foil and the latter is designed to work for both films and aluminum foil. Their different results indicate very different adhesion properties towards starch polymer, which can come from their different crystallinity, as EAA (5%) crystallizes less than EAA (10%).

Comparing the primers vertically between different metallized films, the type of metallized film plays an important role in adhesion. For example, primer PU (30%) has a good adhesion to the metallized biodegradable film but has a poor adhesion to the metallized BOPP film. Conversely, the adhesion of EAA (5%), PVOH (8%), and PEI (12%) all increase with the metallized BOPP film to the metallized biodegradable film. The adhesion results of metallized BOPE fall between the metallized biodegradable and BOPP.

	EAA (10%)	EAA (5%)	PU (30%)	PVOH (8%)	PEI (12%)	No Primer
Coat weight (dry), g/m^2	0.2	0.2	0.4	0.2	0.2	0

EAA: ethylene acrylic acid; PU: polyurethane; PVOH: polyvinyl alcohol; PEI: polyethyleneimine.

III. Estimated coat weights of primers in the adhesion test of starch (Study 2).



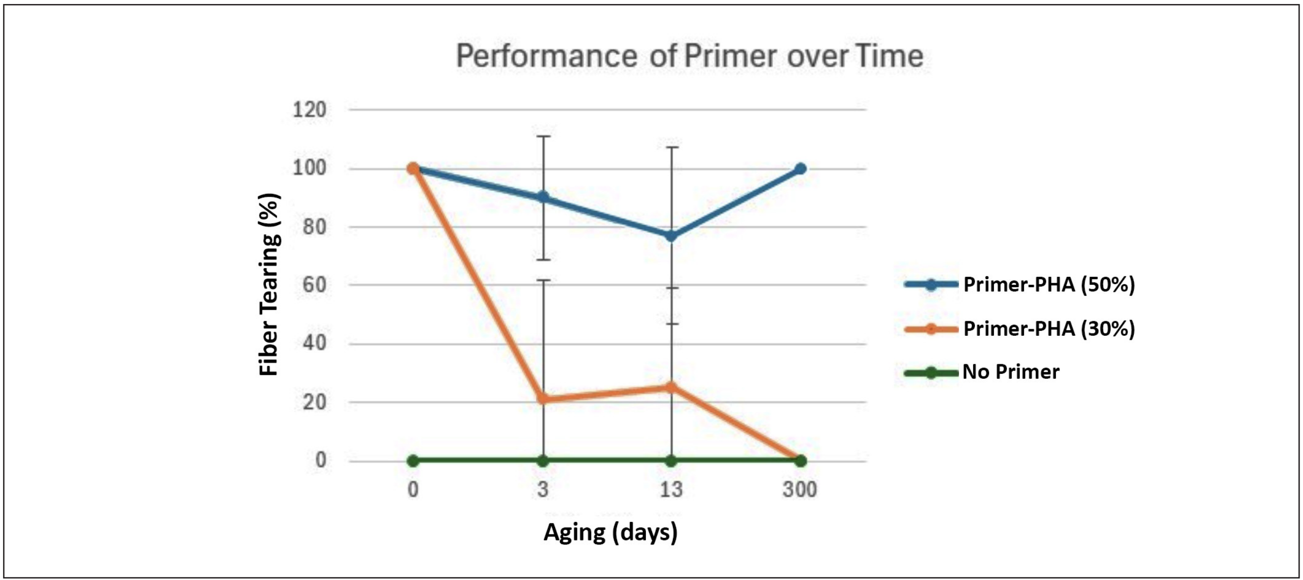
6. Effects of primer on improving adhesion of starch polymer to metallized films (BOPP: biaxially oriented polypropylene; BOPE: biaxially oriented polyethylene).

It is also important to note that the adhesion increases with time. Most of the primers show higher bond strength after a week than the green bond.

The extrusion coating trial in Case Study 2 involved EAA (5%) and PVOH (8%). Their coat weights for each band on the rotary gravure cylinder are shown in **Table IV**. Both primers were diluted in the trial, whose dilution values are also shown in Table IV. Even though PEI (12%) also showed good results in the adhesion test, it was not included in this stage of test due to the fact that PEI, a base, may attack the metallization

Primer	8, BCM	14, BCM	20, BCM	17, BCM	11, BCM
EAA (5%,1:1 dilution), g/m²	0.13–0.16	0.23–0.27	0.33–0.39	0.28–0.33	0.18-0.21
PVOH (8%, 1:4 dilution), g/m²	0.08–0.10	0.15–0.17	0.20–0.25	0.18–0.21	0.11–0.14
BCM: billion cubic microns; EAA: ethylene acrylic acid; PVOH: polyvinyl alcohol.					

IV. Estimated coat weights of primers for each of the five bands on the rotary gravure cylinder used in the extrusion test of starch (Study 2).



7. The use of primer to avert the aging effect of PHA adhesion. The values shown are the average of all coat weights.

layer over time. In the results, both primers showed inseparable bonds between the starch polymer and all three types of metallized films across all the coat weights.

Case Study 3

In Case Study 3, the wetting-out test examined only two primers, a proprietary primer coded as Primer-PHA (solids: 50%) and a biodegradable primer coded as Primer-PHA (solids: 30%). Both showed good compatibility with the paperboard.

The adhesion test was not conducted, because Primer-PHA (50%) had shown good adhesion to polymers similar to PHA. Primer-PHA (30%) had also been tested in trials prior to this study for PHA. The coat weight was at the low end of the recommended range for this primer, which was at 0.1 g/m² (recommended range is 0.1 to 4.8 g/m²). It had been shown that adhesion with this primer had decreased over time. In the new study, its coat weight was significantly increased, which presumably would compensate the loss of adhesion.

Both primers proceeded to the extrusion coating trial after the wetting-out test. The results are shown in **Fig. 7**. **Table V** contains the coat weights of each primer in the extrusion coating trial.

Figure 7 shows the evolution of adhesion strength of PHA to paper. Despite the high coat weights of Primer-PHA (30%) in this trial, its adhesion still decreases over time. The level

Primer	8, BCM	14, BCM	20, BCM	17, BCM	11, BCM
Primer-PHA (50%,1:1 dilution), g/m²	1.3–1.6	2.3–2.7	3.3–3.9	2.7–3.3	1.8–2.1
Primer-PHA (30%, no dilution), g/m²	1.6–1.9	2.7–3.3	3.9–4.7	3.3–4.0	2.1–2.6
PHA: polyhydroxyalkanoates; BCM: billion cubic microns;					

V. Estimated coat weights of primers for each of the five bands on the rotary gravure cylinder in the extrusion test of PHA (Study 3).

of fiber tearing dropped approximately 80% within two weeks and failed completely after 10 months, probably due to the secondary crystallization of the PHA resin [14]. In comparison, the Primer-PHA (50%) brings more consistent adhesion between PHA and the paper. The fiber tearing level remains high even after 10 months. A possible explanation for this difference is that Primer-PHA (50%) is more compatible with PHA than Primer-PHA (30%). Its interaction with PHA at the adhesion interface significantly reduced the secondary crystallization of PHA.

CONCLUSIONS

The complicated physical and chemical properties of new sustainable materials pose new adhesion challenges to the packaging industry. Water-based primers, with their wide variety of chemistries and versatilities, are a straightforward solution to solve these adhesion issues. Whether the issue is due to fast crystallization, second crystallization, low processing temperature, lack of functional groups, or a combination of these factors, water-based primers can help. Here, we have discussed three different types of adhesion issues associated with PVOH, starch, and PHA.

The PVOH is water-soluble and completely dissolves in warm water without leaving a trace, but it has issues adhering to paper due to its rapid crystallization rate. Using our adhesion improvement procedure, we have identified a water-based PEI primer, along with processing conditions to achieve full fiber tearing between the PVOH and paper. Since the completion of this study, this solution has been successfully implemented in several customer trials in the United States and Europe.

Starch polymer is both a bioplastic and biodegradable thermoplastic. Though it has good adhesion to paper, its adhesion to metallized plastic films is poor, which is required to provide moisture resistance and sealability. Through the adhesion improvement procedure, a few primers have been identified to provide strong adhesion between starch and the metallized films. These solutions have been successfully implemented in the new product development with starch polymers.

Likewise, PHA is a bioplastic and biodegradable thermoplastic. Despite its many potential applications, it exhibits fast aging effect of adhesion to paper, probably due to a secondary crystallization process. With the help of a water-based primer, the aging effect has been significantly reduced. This solution will be tested in a future large-scale trial.

As the industry shifts towards more sustainable solutions, it brings innovation with completely new adhesion issues. These case studies demonstrate that water-based primers ensure that these innovations meet both functional and environmental standards for the packaging of tomorrow, enabling converters and brands to reach their sustainability goals faster. **TJ**

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ABOUT THE AUTHORS

This study was driven by the transition of the packaging industry from performance-focused packaging to both performance- and sustainability-focused new packaging designs. There have been few publications on adhesion improvement in biodegradable resins, and research data are rare.

This paper cover studies involving several raw material suppliers and partners, but for commercial reasons, I could not state their names. Organizing raw material from different sources and conducting experiments at these different locations was very challenging. It involved planning and personal skills to complete the study. Also, a sound hypothesis was necessary in preparation for the experiments.

I discovered commercially viable and scalable adhesion improvement solutions for each of the biopolymers that were investigated. It was surprising to find that some of the conclusions went against common wisdom based on conventional packaging materials.

The extrusion coating process at mills can use and benefit from this information. The next step is to scale up these solutions in paper coating to produce more sustainable packaging materials.

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