Flexography Printing Performance of PLA Film

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ABSTRACT: During the past decade polylactide acid (PLA) polymer has been the subject of numerous researches aimed at comparing it with traditional petroleum based polymers for many packaging applications. PLA is biodegradable and derived from agricultural by-products such as corn starch or other starch-rich substances like maize, sugar or wheat. While PLA is currently being used in many packaging applications with well documented performance, little work has been done comparing printing processes and performance. This study presents PLA printing performance and sustainability findings using the common flexography printing process. Various analytical methods were used to evaluate performance and provide recommendations for optimized printing on PLA as compared to PET, oriented PP and oriented PS. Results of this study found that PLA films were comparable in printability and runnability to standard petroleum based flexible packaging films.

1.0 INTRODUCTION

SINCE 1960, the annual generation of municipal solid waste (MSW) has increased more than 65 percent to 251.3 million tons in 2006 [1]. By 2006 material recovery of MSW through recycling and composting accounted for over 32.5 percent of all waste generated, an increase of nearly 83 percent since 1960 [1]. Containers and packaging accounted for nearly 32 percent of all products generated in the MSW in 2006. Plastics which ranked fourth after paper (33.9%), yard trimmings (12.9%), and food scraps (12.4%) accounted for 11.7 percent of the 251 million tons of MSW generated in 2006 [1]. More than 10 percent of all plastic

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containers and packaging, comprising of soft drink, milk and water bottles, were recycled with milk bottles accounting for 31 percent of all bottles [1].

Due to the increasing environmental consciousness of consumers and corporations over the past decade, biodegradable polymers have received ever increasing attention. Amongst commercially available biodegradable polymers are NatureWorks™ Polylactide (PLA), Nodax, Eastar Bio, and Biomax. Biodegradable polymers provide a potential solution to a wide range of environmental concerns typically associated with conventional polymers such as greenhouse gas emissions and sustainability. PLA is derived from lactic acid and has been received well by the medical and packaging industry in recent years. PLA is manufactured from annually renewable sources such as corn and is promoted as being recyclable and compostable.

PLA has been researched internationally for its adaptability to practical applications such as in medical devices and packaging in comparison to traditional petroleum based polymers. Due to its ability to be hydrolyzed, PLA has been studied for use in bio-absorbable medical devices. In de Braekt et al. studied its application for suturing material [2], Bos et al., Laitinen et al., and Matsusue et al. researched its application for surgical implants [3,4,5] and Bodmeier et al., Conti et al., Omelczuh and McGinity, and Suzuki and Price [6,7,8,9] studied its promise in the drug-delivery systems application.

Auras et al. provided an overview of PLA as packaging materials by discussing its physical, optical, rheological, processing, mechanical, solubility, barrier, and degradation properties [10]. Sinclair et al. provided a similar report in their paper on polylactic acid as a commodity packaging plastic [11]. Auras et al. compared food service containers made with oriented PLA to those manufactured using PET and OPS by quantifying their physical, mechanical, barrier and compatibility properties [12,13]. Martino et al. in their research on processing and mechanical characterization of plasticized films for food packaging reported mechanical properties of PLA films for different plasticizer concentrations and preparation conditions [14]. Results of a study involving characterization of L-polylactide and L-polylactide-polycarprolactone co-polymers for use in cheese packaging applications were reported by Plackett et al [15].

The purpose of this study was to research the runnability and printability of PLA and to discover some key considerations when printing on PLA with the flexographic process. There has not been a great deal of published research on PLA—especially on printability. Green Bay Packaging (Green Bay, Wis.) has been working with printability of PLA for more than five years and has performed numerous tests regarding the surface energy, runnability, and printability of PLA [16]. In recent testing Green Bay Packaging is using their soon-to-be patented treated PLA with film surface conditions of no lower than 52 dynes [16]. This allows the polymer to securely anchor any ink process. Green Bay ensures that the surface energy of the film is high enough so that any print engine and most inks will not have problems printing. The company has found during these tests that the key to successful anchorage of ink to the PLA is high surface energy of the film. If a company wants to add a varnish for extra protection of the image, UV varnish by Sun Chemical (item # RCMSV0482232) is recommended [16]. The UV over-varnish doesn't contain silicone, and therefore can biodegrade and compost easily. Green Bay Packaging has not experienced problems with the runnability of PLA. According to them PLA has good stiffness and should run well on any press—the rigidity helps with registration, trapping, and tension on line [16].

2.0 MATERIALS AND METHODS

2.1 Ink Adhesion

An ink adhesion test was preformed using a lab ink proofer prior to running the polymer films on press. The surface energy of PLA was tested using Accudyne test solution swabs to sample the film. A large difference between the dyne level of surface energy in a material and the dyne level of surface tension in ink, most often results in better print quality. The optimal surface energy of the substrate is dependent on the ink system but is typically above thirty-eight dynes. The surface energy of the film should be higher than the surface tension of ink because it is more practical and economical for a printer to change the surface tension of a material than to change the inks on their press. Surface-treated film (corona or plasma treated) creates higher surface energy polymers. Most water-based inks have a surface tension of about 36 dynes. The water-based inks used in this experiment where designed for PET and PP plastic films, and therefore leads to better ink adhesion for those particular films. Inks formulated specifically for PLA were uncommon at the time. A draw-down test with the anilox-roll hand proofer was used to test ink adhesion to the film. Once blown-dry, a crinkle test determined that the adhesion was acceptable to print on press.

Prior to running the film on the press, a test target was created in Adobe Illustrator to produce a plate and is shown in Figure 1. The image contains vector and raster images, a solid strip, tick marks an eighth inch apart along the lateral edge, slur targets, multiple point sizes, regular and reverse print, 1 through 100 percent density patches, and some gradient strips. The file was RIPed through Esko's Cyrel Digital Imager (CDI) Spark System using Esko's Suite 7 workflow. The plate was set at 150 line screen ruling, 68 degree angle using a circular dot shape. The vertical distortion scaling was set to 96.751 percent. The CDI system was calibrated prior to output with a focus search, stain test, and midtone density test.

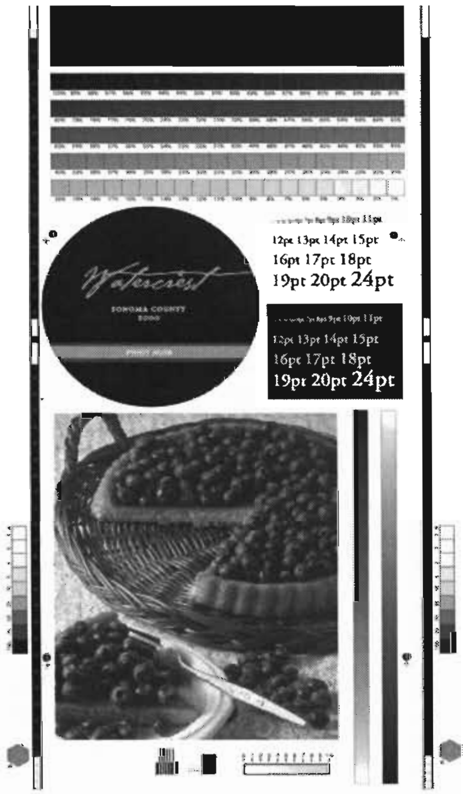

Figure 1. *Test target used to produce a plate.*

The plate was initially placed into the Dupont Cyrel FAST Exposure Unit for 23 seconds for the back exposure. The carbon masked plate material was positioned into the CDI, in which a laser then began to ablate the mask creating a negative image area. Following the setting of the floor and relief through the initial exposure, the plate was polymerized by exposing the emulsion side using a main light source for eight minutes. The plate was then carried to the Cyrel FAST Dupont Processor to remove the unexposed photopolymer prior to detack and post-exposure. Prior to the plate running on the press, a BetaFlex334 system was used to measure the dot area patches on the plate. The finished plate was mounted on a 96 tooth, 1/8 CP cylinder using the Mark Andy Conversource PM-160.

2.2 Runnability

Conventional methods were performed to setup the press. There were many variables controlled during the press run. Many Flexo variables are hard to control because they involve manual deck settings, which makes them more prone to error. Constants that can be controlled include: viscosity, pH, anilox roll, speed, dryer, and tension. Plate and anilox and Plate to impression are difficult to repeat precisely on a Mark Andy 2200 because of the manual deck settings. Environmental Inks and Coatings Film Ink III system was shipped at a viscosity of 25–30 seconds on a #2 Zahn cup with a pH of 9.0–9.3. Prior to running the ink on press, a #2 Zahn cup was used to measure the viscosity of the ink. It measured at 50.9 seconds, which is higher than normal. Too low pH levels usually result in an ink-transferring problem. The uncut ink measured at a pH level of 9.44. The desired level is between 9–9.3 for the Film III Ink System on a Flexographic press. However, the average range for water-based inks is between 8–9.5, therefore the pH was within the tolerance level.

Water-based inks are more difficult to control on the press. Their viscosity and pH levels can change with time on the press. As the press continues to run, the amine may evaporate and the pH level decreases and the viscosity increases. However, the run was so short that the viscosity and pH remained constant throughout the pressrun. Environmental Inks recommended an addition of under ten percent of an ammonia substitute every half hour. The press only ran an hour for about 700 feet of film.

To maximize repeatability and consistency, the impression was controlled using check gauges that had the same diameter of the pitch surface being used. The impression was adjusted by hand and varied with polymer thickness, which makes it difficult to replicate exactly. Therefore, it contributes to the reason for running all the plastics on the same day, to try to reduce the variables. The anilox roll was also constant. A 2.48 volume, 600 line count, 60°, Harper roll was chosen for the Mark Andy 2200 seven-inch Flexographic press. The anilox roll was selected based on the 150 resolution of the plate to achieve appropriate cell count. The press speed was set at 50 feet per minute, and the dryer was positioned at stage 3, which was approximately 167° F. The speed and dryer settings were chosen because there are challenges with film inks drying on the plastic with lower heats and faster speeds on an in-line press. The tension was set at 20 psi.

The five films were run on the Mark Andy press using water-based inks with relative ease. The order in which the webs of film were spliced in were: white PLA, clear PLA, PET, OPP, and OPS. A little over a hundred feet of each material were used. Some of the visual potential runnability problems that occurred on press included problems running the OPS and having dirty print. The OPS was very brittle and broke easily on the in-line press. There were two web breaks when running OPS. And lastly, the print became increasingly dirty throughout the press run. There were many predictions to the reason for the dirty print that are discussed later.

2.3 Printability

The tests conducted to determine printability were: dot area, tone reproduction, optical/reflective density, specular gloss, dot shape, visual tests, rub resistance, adhesion, and tensile strength. The dot area and tone reproduction of the printed material were determined with a BetaFlex334 system. The tonal patches on each film were measured in increments of five, from one to a hundred. An Xrite 528 Spectrodensitometer was used to measure the densities of a solid black area on each film. The Novo-glass Statistical Glossmeter (Rhopoint 60 degree angle model) determined the specular gloss of each film using the same solid black area. Horizontal and vertical readings were taken. The ImageXpert system was used to determine the roundness of the five percent dots on each film. A digital image was captured of the five percent dots using SonyXCD-X710 video camera. The dot roundness was defined by the ratio of the circumference of a circle with the same average radius to the perimeter length of the dot. Some other digital images were captured for visual comparisons, using the same video camera system. They include samples of bridging at five percent dot and samples of font type quality.

3.0 RESULTS AND DISCUSSION

3.1 Dot Gain

There was no substantial difference in the trend of dot gain in the curve across the different films. The largest dot gain occurred between 35 and 55 for all of the films. The white PLA film had a 29.3 percent dot gain at 40 percent dot. The clear PLA film had a 24.7 percent dot gain at 40 percent dot. The PET film had a 31.1 percent dot gain at 40 percent dot. The OPP film had a 28.9 percent dot gain at 40 percent dot. The OPS film had a 27.9 percent dot gain at 40 percent dot. The plastic film with the highest dot gain was PET with 31.1 percent at 40 percent dot. Figure 2 below shows the dot gain results. The dot area of the printed material was determined with the Xrite 528 system. The density patches on each film were measured in increments of five, from one to a hundred.

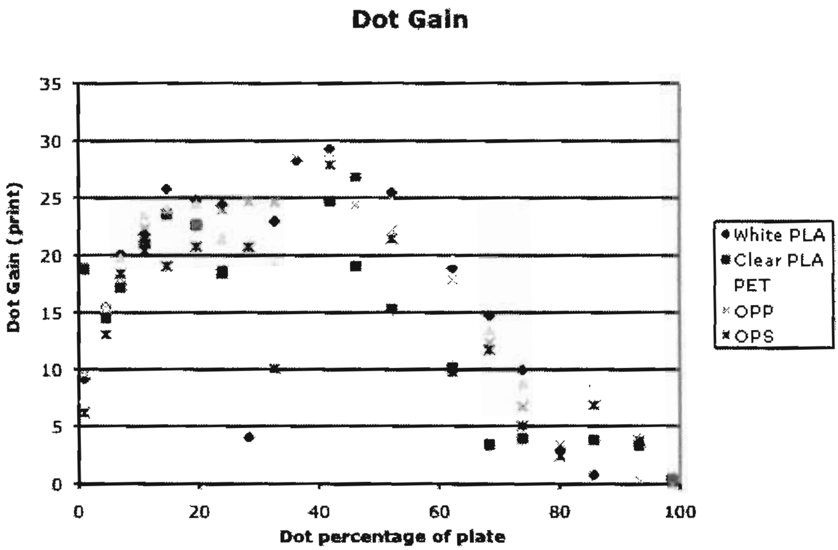

Figure 2. *Dot gain results.*

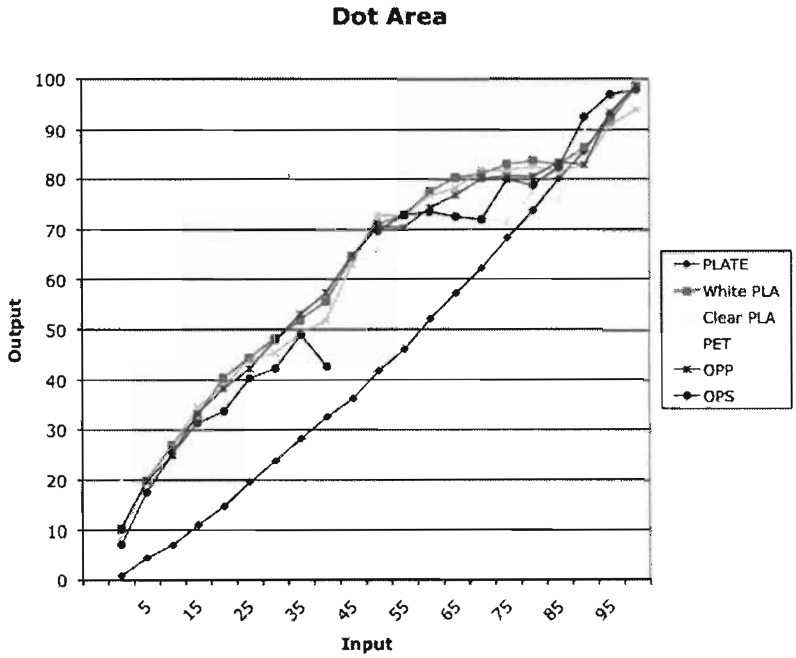

Figure 3. Tone reproduction of printed material.

3.2 Tone Reproduction

There was no substantial difference in the trend of the tone reproduction curves across the different films. However, all of the clear films experienced difficulties while being read by the instrument, as shown by the jagged lines in Figure 3. Therefore, it was hard to compare which plastic film had the best tone reproduction. The white PLA appears to have the smoothest curve, which makes it easier to compensate for dot gain in prepress.

3.3 Optical/Reflective Density

The FIRST density standard is 1.4 for black ink on film products using narrow web. All of the densities printed had higher densities than the standard. The chosen anilox roll was not optimized for the desired ink density and lay down. The white PLA film had the highest density over the other films. The clear PLA has the highest density over the clear film. PLA films may achieve higher densities than other films.

Table 1. *The Xrite 528 Spectrodensitometer was used to Measure the Densities of a Solid Black Area on Each Film.*

Films	White PLA	Clear PLA	PET	OPP	OPS
Densities	1.68	1.71	1.56	1.68	1.66
	1.78	1.71	1.61	1.61	1.63
	1.70	1.66	1.60	1.73	1.59
	1.70	1.66	1.61	1.65	1.68
Average	**1.72**	**1.68**	**1.60**	**1.67**	**1.64**
Standard Deviation	**0.04**	**0.03**	**0.02**	**0.05**	**0.04**

3.4 Dyne Levels

The tests showed that the natural dyne level of clear PLA is about 38 and the white PLA had a dyne level of about 36. The other films had similar dynes levels: PET had about 39 dynes, OPP had about 37 dynes, and OPS had about 37 dynes.

3.5 Type Quality

Type Quality Images were captured for visual comparisons, using the ImageXpert system. The results for type quality were in the following order from best to worst: white PLA, PET, OPP, clear PLA and OPS films. The images are shown in Figure 4.

3.6 Dot Shape

The ImageXpert system was used to determine the roundness of the five percent dots on each film. The dot roundness was defined by the ratio of the circumference of a circle with the same average radius to the perimeter length of the dot. The five percent dot was chosen to compare

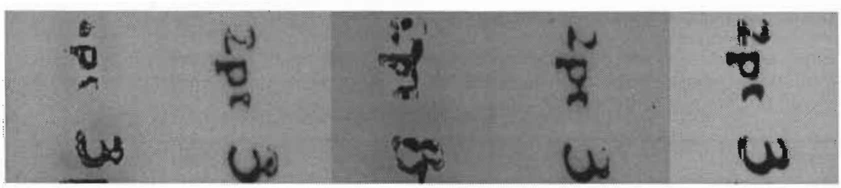

Figure 4. *Type quality images.*

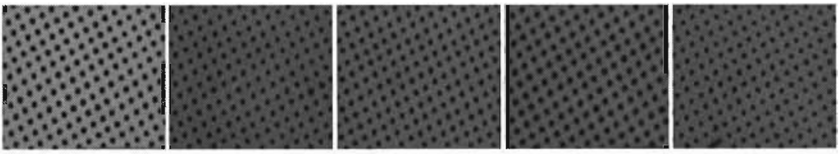

Figure 5. Digital images of the five percent dots.

the roundness. The ideal number to achieve is one. The PET film is the closest to achieving this standard. The PET film also has the highest dyne level, which may correspond to being the closest to one.

3.7 Specular Gloss

The Novo-glass Statistical Glossmeter (Rhopoint 60 degree angle model) determined the specular gloss of each film using the same solid black area. Horizontal and vertical readings were taken as shown in table 3 below. With no lamination, high gloss is more desired to achieve a better print appearance. The clear PLA has the highest gloss compared to all of the films, and has the highest gloss compared to the other clear film. The white PLA has the highest gloss compared to the other white films.

3.8 Rub Resistance

The TMI Ink Rub Tester determined the rub resistance of each material. The two by four inch and two and a half by six inch strips were cut and taped onto the base and test block. The four-pound test block was placed on top of the base. The settings were adjusted to 100 cycles at 42 cycles per minute.

A visual test was performed on the rub test samples. The clear PLA film had the poorest rub resistance, closely followed by the white PLA film. The OPS film had the next worse rub resistance. The OPP and PET films had the best rub resistance.

Table 2. Dot Roundness Results

White PLA	Clear PLA	PET	OPP	OPS
0.62	0.62	0.82	0.57	0.53

Table 3. Specular Gloss Results.

Gloss	White PLA	Clear PLA	PET	OPP	OPS
Horizontal	57.65	65.70	58.60	46.88	56.80
Vertical	62.60	75.38	46.38	48.18	62.18
Average	**60.13**	**70.54**	**52.49**	**47.53**	**59.49**

3.9 Ink Adhesion

Scotch 3M Premuim Grade Transparent Cellophane 610 Tape was used to perform the adhesion test. A small two-inch piece of tape was placed in approximately the same spot on every film and immediately pulled off after slightly patting it down. And lastly, the Testometric CX M350-5KN system measured the elasticity, force, and breaking point of each film. An ASTM slitter cut one by eleven inch strips prior to being placed into the machine.

A visual test was performed on the ink adhesion samples. The white PLA film had the poorest ink adhesion, closely followed by the clear PLA film. The OPS film had the next worse ink adhesion. The OPP and PET films had the best ink adhesion. The OPP film had the best adhesion.

3.10 Runnability

Some of the potential runnability problems that occurred on press included problems running the OPS and having dirty print. This test was run on a narrow-web in-line press. In commercial applications, these materials would often be run on a wide-web CI press, offering better tension control and reduced potential for web breaks.

Table 4. Tensile Strength Results.

	Force @ Peak (N)	Elongation @ Break (mm)	Time (sec)
White PLA	151.01	50.06	0.50
Clear PLA	173.70	41.38	0.41
PET	106.86	207.92	2.08
OPP	106.12	122.69	1.23
OPS	105.56	5.65	0.06

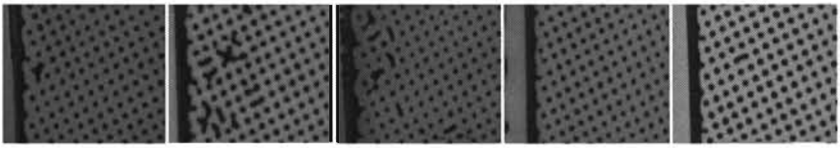

Figure 6. Images were captured for visual comparisons, using the ImageXpert system. The samples of the bridging are in order of CPLA, OPP, OPS, PET, WPLA.

3.11 Tensile Strength

Tensile strength measures the force required to pull a substrate to the point of when it breaks. The Testometric CX M350-5KN system measured the elasticity, force, and breaking point of each film. An ASTM sample cutter cut one by eleven inch strips prior to being placed into the machine. The speed of the machine was 100 mm/min. The OPS used the least force to break, which indicates that this film has the worse tensile strength. This was observed on press with the two web breaks. The clear PLA has the best tensile strength, and least likely to stretch and distort on press.

3.12 Dirty Print

The print became increasingly dirtier throughout the press run. There was an increased incidence of dot bridging the longer the press was running. The order the films ran on press were: white PLA, clear PLA, PET,

Table 5. *Summary of Findings. (1= best/highest to 5=worst/least).*

Gloss	White PLA	Clear PLA	PET	OPP	OPS
Dyne	4	2	1	3	3
Dot Gain	4	1	5	3	2
Tone Reproduction	1	4	3	2	5
Density	1	2	5	3	4
Type Quality	1	4	2	3	5
Dot Shape	2	2	1	3	4
Specular Gloss	2	1	4	5	3
Rub Resistance	4	5	1	2	3
Ink Adhesion	4	5	1	2	3
Tensile Strength	2	1	3	4	5
Dirty Print	1	2	3	4	5
Average Score	**2.36**	**2.64**	**2.64**	**3.09**	**3.82**

OPP, and OPS. The OPS film seemed to have the most bridging. There were many predictions to the reason for the dirty print. Some articles have suggested that it could be caused from the plate, ink, anilox roll, and the doctor blade. In this research, the only other variable that is time sensitive is the pH and viscosity. The recommended viscosity was 25–30 seconds with a pH of 9.0–9.3. The ink ran on press with a higher viscosity and pH than was recommended. Since the pH level starts to decrease and viscosity increase the longer it is run on press, an ink-transferring problem usually occurs leading to increased incidence of bridging. The pH and viscosity were only controlled at the beginning of the press run; therefore it cannot be determined in this study. More research would need to be performed to confirm this relationship.

4.0 CONCLUSIONS

According to this summary of findings chart, it seems that the white and clear PLA films are most comparable to the PET film. Even though the ink was formulated for PP and PET, the white and clear PLA outperformed OPP in the majority of the printability and runnability tests. The OPS film performed the worst compared to the other plastic films. The white PLA film outperformed the PET film, which was also white. The clear PLA film performed equally as well as the PET film. If the PLA films used custom formulated ink, they would have likely outperformed all of the films. NatureWorks recommends using Akzo Nobel's Hydrokett3000 or Hydrofilm 4000 water-base inks for good ink adhesion.

Given time, PLA may replace some of the most common plastic films used in the food industry. It is difficult for a new film to break into a market that has twenty or more years of established film lines. Advancements are continuously being made to the structure of PLA to enable the plastic to be used in more applications. The PLA films are already ideal for many of the same applications other petroleum-derived films are used for today. They can be used for pressure sensitive labels, shrink sleeves, cut and stack labels, laminates, and more. PLA films can be produced both as mono-layer or may be co-extruded, with cast or blown film extrusion methods presently being the most common. The popularity of sustainable films will continue to increase as companies understand the savings of using annually renewable resources. There is an obvious momentum in the use of PLA, and it will continue to become increasingly competitive with traditional petroleum-based films in the future.

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