Printability Analysis of Flexographic printing on Compostable films

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THAILAND’S BIOPLASTICS INDUSTRY
Global production capacities of Bioplastics

- Worldwide consumption of bioplastics has increased more than 600% in the past decades and expected to reach 40% market share of global plastics market in 2030.
- Global production capacity of bioplastics is forecasted to grow by 50 percent, from 4.2 million tons in 2016 to roughly 6.1 million tons in 2021.
- Asia will continue as a major production hub. In 2021, it is expected that more than 45 percent of bioplastics will be produced in Asia.

Source: European Bioplastics, Nova Institute
Global production capacities of bioplastics by material types (in 2016)

Total: 4.16 million tonnes

- 41.2% PUR
- 4.8% PE
- 3.5% PA
- 2.2% PET
- 1.6% PHA
- 5.1% PLA
- 2.8% PBS
- 2.5% PBAT
- 0.8% Other (biodegradable)
- 10.3% Starch blends
- 0.0% PEF

Bio-based/non-biodegradable: 76.8%
Biodegradable: 23.2%

*PEF is currently in development and predicted to be available in commercial scale in 2020.

Global production capacities of bioplastics by market segment

Source: European Bioplastics, Nova Institute
Biopolymer manufacturers and Bioplastics converters in Thailand

- Thailand is ASEAN’s second largest exporter of plastic products after Singapore, and ranked 14th in the world in 2016.
- With over 3,000 plastics converters, Thailand is well-established in the downstream industries with the capability to produce a wide range of products such as bioplastics bag, biodegradable box, etc.
- The country’s top destination of bioplastics products export includes the European Union, the United States, and Japan.

Source: International Trade Center

Leading Biopolymer manufacturers

[Images of biopolymer manufacturers]

Leading Bioplastics converters

[Images of bioplastics converters]
Objectives of research

• To analyze the printability of flexography on compostable films commercialized in the Thai market such as PLA/PBAT and PBAT/starch.
• To comply with EN 13432 standard by using water based ink

Note: these compostable products are certified according to EN 13432 / 14995 standards.
PLA - Polylactic acid

- It is a well-known biodegradable aliphatic polyester resin.
- PLA is expected to be the largest segment, in terms of volume, in the bioplastic market.
- The growth of PLA is driven by its superior mechanical properties and ease of processability.
- Due to high glass transition temperature (58°C), this makes it easily brittle or fragile at normal temperature. Additives are needed to blend for improving this obstacle.
- PLA has similar mechanical properties to PET polymer.
• PBAT bioplastics is made from fossil resources and it can be considered as one of the sustainable materials of the generation of modern “green materials”.

• It has similar properties like low density polyethylene (LDPE) such as high elongation at break and very flexible.

• The largest volume product is flexible film for packaging, e.g compostable shopping bags.

• Due to High production cost and low thermo-physical and mechanical resistance, it require additives such as natural fibers and cellulose derivatives or PLA to improve properties and cost.
Suitability of printing Inks within the present regulatory frame of EN 13432

• “Compostability” in relation to printing inks for packaging has been seen in conjunction with the compostability of the substrate.

• The compostability of printed packaging largely depends on the properties of the substrate. Printing ink layers are very thin (1 to max. 5 µm) and account for only 0.5 to a maximum of 3% of the packaging by weight.

• Consequently, a fundamentally new formulation of printing inks, comprising of biodegradable and/or natural binders and pigments, does not appear necessary.
Recommendation of printing inks in compliant with EN 13432

- Each constituent has to remain < 1% and the sum of all constituents without certification has to remain < 5% by weight –

- Example: 50 g/m² biodegradable film, 1 g/m² ink grammage
  - solid print of 1 colour shade: the ink part is non compliant with EN 13432, as its share is approximately 2%;
  - 49 % ink coverage: the ink part is compliant with EN 13432, as its share remains < 1%
  - full-surface process print: the ink part is compliant with EN 13432, as the share of each colour is 0,5% and the sum of the four colours is 2%.

Note: The printing ink type should be tested for eco-toxicity on the compost in accordance with both tests of EN 13432 chapter 8.2 and Annex E. There must be no relevant negative effects on plant growth.
Flexographic printing – important parameters

- anilox line screen / cell type and cell volume
- plate types/ thickness and hardness
- printing pressure
- printing speed
- packing types
Flexographic printing

Printability
- density / tone value
- tone reproduction
- print smoothness
- print uniformity
- print contrast
- wettability
- rub resistance
Experimental

- **PLA/PBAT blend** (40:60) at 100 micron thickness and **PBAT/corn starch** (50/50) at 40 micron thickness were printed by a narrow-web flexo press.

- **Test form** (gray scale 0 – 100%) was designed for making flexo plate. Image resolution was 133 lpi.

- **Black water acrylic based flexo ink** was developed by Panorama Soy Ink Company in Thailand.

- To analyze surface energy of substrate, surface wettability.

- To analyze the effects of flexographic printing related to printability:
  - the performance of water acrylic based ink
  - the effect of anilox line screen from 400 to 700 lpi
  - printing speed

- **Printability** was analyzed:
  - wettability
  - solid density / TVI
  - tone reproduction
  - print uniformity
  - surface roughness
  - rub resistance
Equipment and materials

- **Zahn cup No. 3** to measure viscosity of ink.
- **VDO capturing device** for evaluating sessile ink drop.
- **Dyne-liquid pen** to determine surface energy of substrates.
- **Narrow web Nilpeter-FB 3300 S flexo press** + **medium soft type packing** by TESA®+ **digital flexo plate** 1.14 mm thickness and hardness 64 shore A.
- **JSM-6400 Scanning Electron Microscope (SEM)** to analyze surface morphology and the body of films.
- **Scanning Probe Microscope (SPM) Controller type NanoScope IV** to analyze the surface roughness.
- **Sutherland Ink Rub Tester** to measure rub resistance.
- **Reflection densitometer** to evaluate tone reproduction of prints.
# PLA/PBAT vs PBAT/starch

## Physical properties of two compostable products

<table>
<thead>
<tr>
<th>Samples</th>
<th>Tensile strength (Kg/mm²)</th>
<th>Elongation* (%)</th>
<th>Density (g/cm³)</th>
<th>Surface energy (dyne/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MD</td>
<td>TD</td>
<td>MD</td>
<td>TD</td>
</tr>
<tr>
<td>PLA/PBAT</td>
<td>1.68</td>
<td>1.86</td>
<td>443</td>
<td>460</td>
</tr>
<tr>
<td>PBAT/starch</td>
<td>2.30</td>
<td>1.42</td>
<td>461</td>
<td>744</td>
</tr>
</tbody>
</table>

*at break: ASTM-D882-02 / MD: machine direction, TD: transverse direction

- The PLA (Tg = 58 °C, Tm = 155 °C) and PBAT (Tg = −29 °C, Tm = 110–115 °C) resins were utilized to produce blown films.
- Two recipe of blended products were provided by two manufacturers in Thailand. One was PLA/PBAT blend (40:60) at 100 micron thickness and another PBAT/corn starch (50/50) at 40 micron thickness.
- Thermoplastic starch (TPS) was blended with PBAT in prior before blowing film. These resins were supplied by FKuR (Bio-Flex©) and Novamont (Mater-Bi©).
Water acrylic based ink

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Amount(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>flush pigment</td>
<td>20</td>
</tr>
<tr>
<td>water</td>
<td>20</td>
</tr>
<tr>
<td>polypropylene glycol</td>
<td>5-10</td>
</tr>
<tr>
<td>acrylic copolymer</td>
<td>35-45</td>
</tr>
<tr>
<td>ethoxylated alcohols</td>
<td>5-10</td>
</tr>
</tbody>
</table>

- Surface tension of ink was 40 mN/m (dyne/cm).
- Viscosity of ink was controlled at 20-23 seconds.
Results: 1. surface morphology of compostable films

- PLA/PBAT film had its surface morphology fractured as PBAT’s molecular chain was more flexible than that of PLA and was easier to entangle.
- Oval cavities and enclosed round PBAT particles were visible in the film body.
- **PBAT/starch film**: the appearance of fractured surface was rugged. Some of starch granules were removed from the fracture surface leaving behind cavities.
- PLA/PBAT film gave RMS surface roughness higher than that of PBAT/starch film.
2. Comparison of solid density on two compostable films

- The increase of corona dosage had no difference among 500 – 1,500 watts-min/m².
- The amount of corona treatment at 500 watts-min/m² was enough.
- Anilox line screen at 700 lpi was considered to be suitable much more than 400 and 600 lpi.
3. Effect of anilox line screen on Tone Value Increase

- Lower anilox line screen can create the dipping problem. This phenomenon gives loss of detail and image sharpness.
- Higher anilox line screen tends to give ink transfer problem from anilox cells to printing plate.
- The use of water based ink requires high printing speed and hot air drying to minimize retention time of ink on the films’ surface before drying.

![Graph illustrating the effect of anilox line screen on TVI values](image_url)

Effect of anilox line screen (lpi) on TVI values of printed image on PLA/PBAT (Corona treatment at 500 watt-min/m²)
Explanation

• PLA/PBAT film showed higher TVI values than those of PBAT/starch film in all printing conditions. It was because PLA/PBAT film had high surface roughness and porous structure.

• Printing condition using anilox line screen 700 lpi and printing speed at 30 m/min was preferable by which the maximum solid tone density fell in the range of 1.5 -1.6 and the obtained highest print contrast reached about 25% and 18% for PBAT/starch and PLA/PBAT films respectively.

• PBAT/starch film gave shadow detail or print contrast better than that of PLA/PBAT film. It was due to the differences in surface structure of two films.

• We recommended the corona dosage was at 500 watt-min/m².
4. Tone reproduction of prints

Printed images on compostable film samples using anilox line screen 700 lpi and printing speed at 30 m/min

Comparison of tone reproduction curves on printed PLA/PBAT and PBAT/starch film samples
5. surface wettability

- Contact angle measurement showed that these film samples were hydrophobic nature.
- ink did not penetrate well in the surface within 1 second.
- Lower contact angles come from the effect of surface roughness.
- Wet and dry rub resistance of print tended to be poor.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Ink</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLA/PBAT</td>
<td>29°</td>
<td>87°</td>
</tr>
<tr>
<td>PBAT/Starch</td>
<td>34°</td>
<td>92°</td>
</tr>
</tbody>
</table>

ink’s surface tension and viscosity shall be readjusted to improve the rapid penetration and wettability.
Non treated films gave explicitly unsatisfactory printed quality result by poor ink wettability.

- Both film samples had surface energy at about 38 dyne/cm.
- Print uniformity seemed to relate to the increase of corona dosage.
- Corona 1,500 watt-min/m² damaged both film surfaces by which print non-uniformity reappeared.
- At 1,500 watt-min/m², the surface energy of both films was increased to the unsuitable level at 50 dyne/cm.
6. Surface roughness (Mean roughness – nm)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Non treatment</th>
<th>Corona 500</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLA/PBAT</td>
<td>435.3 nm</td>
<td>541.0 nm</td>
</tr>
<tr>
<td>PBAT/Starch</td>
<td>207.8 nm</td>
<td>236.7 nm</td>
</tr>
</tbody>
</table>
Surface roughness of non-prints and prints (at Corona 500 watt-min/m²)

PBAT/starch

Non-print

Mean Roughness = 236.7 nm

Print

Mean Roughness = 181.2 nm

PLA/PBAT

Non-print

Mean Roughness = 541.0 nm

Print

Mean Roughness = 344.1 nm
7. Rub resistance (at corona 500 watt-min/m², anilox line screen 700 lpi, printing speed 30 m/min)

<table>
<thead>
<tr>
<th></th>
<th>PBAT/starch</th>
<th></th>
<th>PLA/PBAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Rub Tester</td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
<td><img src="image3" alt="Image" /></td>
</tr>
<tr>
<td>5 rounds</td>
<td><img src="image5" alt="Image" /></td>
<td><img src="image6" alt="Image" /></td>
<td><img src="image7" alt="Image" /></td>
</tr>
<tr>
<td>10 rounds</td>
<td><img src="image9" alt="Image" /></td>
<td><img src="image10" alt="Image" /></td>
<td><img src="image11" alt="Image" /></td>
</tr>
<tr>
<td>15 rounds</td>
<td><img src="image13" alt="Image" /></td>
<td><img src="image14" alt="Image" /></td>
<td><img src="image15" alt="Image" /></td>
</tr>
<tr>
<td>30 rounds</td>
<td><img src="image17" alt="Image" /></td>
<td><img src="image18" alt="Image" /></td>
<td><img src="image19" alt="Image" /></td>
</tr>
<tr>
<td>100 rounds</td>
<td><img src="image21" alt="Image" /></td>
<td><img src="image22" alt="Image" /></td>
<td><img src="image23" alt="Image" /></td>
</tr>
<tr>
<td>500 rounds</td>
<td><img src="image25" alt="Image" /></td>
<td><img src="image26" alt="Image" /></td>
<td><img src="image27" alt="Image" /></td>
</tr>
<tr>
<td>1000 rounds</td>
<td><img src="image29" alt="Image" /></td>
<td><img src="image30" alt="Image" /></td>
<td><img src="image31" alt="Image" /></td>
</tr>
</tbody>
</table>

Based on Sutherland Rub Tester using a motor-driven instrument for moving a 4 pound-weights over a printed film.
Conclusions

- It is possible to apply flexographic printing on compostable PLA/PBAT and PBAT/starch films.

- **Film structures on the surface and voids** play an important role in print quality such as density and tone value increase.

- **Hydrophobic property** of both films needs to be improved by corona treatment to achieve print uniformity and ink rub resistance.

- **Corona dosage** has limitation due to the weakness of film surfaces.

- **Anilox line screen 700 lpi** and **printing speed at 30 m/min** are preferable to achieve optimum tone reproduction and print contrast. This will be based on the **image resolution on flexo plate 133 lpi** and the **corona dosage at 500 watt-min/m²**.

- Although **PBAT/starch film showed print quality better than that of PLA/PBAT film**, but the **print contrast** still needs to be improved.

- PBAT/starch film showed **ink rub resistance** better than that of PLA/PBAT film.
Thank you very much