Specification of Metallized Films and Substrates

AIMCAL Fall Technical Meeting
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EMMOUNT Technologies
Specifying Metallized Films & Substrates

• End use dependent
  – Decorative application
  – Functional application
    • Developed properties

• Base sheet properties
  – End use dependent
    • Property development
    • Mechanical properties
    • Thermal properties

• Metallizer dependent
  – Web handling properties
    • Surface properties
    • Mechanical properties
  – Thermal properties
  – Drive characteristics
    • Minimum tension
  – Boat design
    • Distance to web
    • Boat spacing
Substrate in Metallization

A material with specific properties which is designed as a foundation to support and carry an additional layer of vacuum deposited metal.

It supplies the basic strength, stability and compatibility properties needed by the product and the added metal (aluminum) layer.
Design and Specification

• The product design and specifications must come from a process designed to determine the fitness for use of the product and the substitute quality characteristics used to measure the films performance in use.

• Fitness for use gives the product design.

• Substitute quality characteristics gives the film specification.
Fitness-For-Use

- based upon the performance needs and request of the customer.
- This information has to be obtained by a series of conversations or interviews with the customer about the expectations of performance for the product he will be packaging or converting. The purpose of the conversation is to obtain this information, in the customer’s language.
Fitness-For-Use Categories

- product designer should be searching for three categories of information;
  - performance characteristics which are required to be met to insure that the new product works (it is FFU),
  - performance levels or attributes which if met will delight the customer by exceeding his expectations.
    - These performance levels need not be required by the product for generating functional product or may simply represent a better performance level than required for FFU.
  - performance characteristics found in competitive products, which must be matched or about which the customer must be educated.
What are Substitute Quality Characteristics?

Film property values and performance measures derived from the FFU statements and performance measures by direct experimentation.

Values represent the quality control targets for film manufacture, which are to be used to control the consistency and quality of the film being manufactured.
Where do I Find Substitute Quality Characteristics?

Film properties should be developed from experiments, which demonstrate the fitness for use characteristic specific to the end use.

Film properties which do not impact on the performance of the film in the end use need not be measured or controlled but may be part of the film profile or typical values.
Metallized Film & Substrate Properties
Principal Substrate Properties

- Cost
- Metallizing Surface Energy
- Tensile strength
- Stiffness
- Stability
  - Thermal
  - Environmental
- Gas Transmission

- Winding Properties
- Sealability
- Durability
- Tear strength
- Impact strength
- Lubricity
- Abrasion Resistance
- Dielectric properties
Metallizing Substrates: Key Substrate Properties

- Paper
- Polyester
- Polypropylene
- Polyethylene
- Polymides
- Polyamides
- Others

- Stability
  - thermal & environmental
- MD Modulus
- Yield Strength
- Yield Point
- Film Thickness / Web width
- Shrinkage; % and Temperature
- Coefficient of Friction
- Metallization Surface
  - Surface energy
  - Surface gloss
Metallized Film Characteristics

Packaging Films
- Supplies Light Barrier
- Moisture Barrier Essentially the Same
  - Aluminium Supplies the Barrier
- Oxygen Barrier Dependent on Surface
  - Interface Controls the Barrier
- Chemical Barrier Extremely Variable
  - Permeant / Base Polymer Interaction
  - Metallizing Layer can Control

Electronic or capacitor Film
- Surface resistance
- Dielectric strength
- Oil resistance
- Surface defects
Metallizer Quality Measures

- “Appearance”
- Optical density level & variability
- Metal adhesion
- Gas & Moisture Barrier
- Surface resistivity
- Roll conformation
- Metal pickoff
Appearance

- Bright “Shiny” Surface
  - Controlled by law angle gloss
  - Gloss controlled by surface smoothness
- Brushed appearance
  - Uniform surface scratching
- Matte Surface
  - Controlled surface roughness

RAYLEIGH MODEL 550nm

\[ D_h = \lambda / (8 \sin I) \]
Surface Treatment Level: must determine experimentally

- Low level for metal uniformity
- Select type of treatment
  - Impacts surface chemistry
- Will impact:
  - Optical Density
  - Metal adhesion
  - Barrier Levels
- Over treatment possible
  - Lowers metal adhesion
- Online + Plasma
- No back side treatment
Light Barrier (OD) Specification

LIGHT TRANSMISSION VS. OPTICAL DENSITY

\[ T\% = \text{Antilog}(2-\text{OD}) \]
Surface Resistivity Specification

Surface Resistance to Optical Density for Aluminum Metallized 48 Gauge Polyester Film

\[ SR = 0.8626 \times OD^2 - 6.1352 \times OD + 11.543 \]

\[ R^2 = 0.8623 \]
Barrier Example

• Determine required permeability
  – 20 ppm oxygen ruins product
  – Package area 100 in\(^2\)
  – 1 pound (454 gms) of product in package

• Calculate
  – 20 ppm = 0.00908 gm of oxygen
  – \(O_2\) mol wt = 32gm/mol \(\Rightarrow\) 0.000284 moles
  – 1 mole = 22414 cc at STP \(\Rightarrow\) 6.36 cc total to ruin product

• Permeability required
## Required Permeability
for 6.36 cc oxygen gain

<table>
<thead>
<tr>
<th>Oxygen gain to failure</th>
<th>20 ppm</th>
<th>200 ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shelf life</td>
<td>Permeability: cc/100 in²/day</td>
<td>Permeability: cc/100 in²/day</td>
</tr>
<tr>
<td>30 days</td>
<td>0.212</td>
<td>2.12</td>
</tr>
<tr>
<td>90 days</td>
<td>0.0707</td>
<td>0.707</td>
</tr>
<tr>
<td>120 days</td>
<td>0.053</td>
<td>0.50</td>
</tr>
<tr>
<td>1 year</td>
<td>0.0174</td>
<td>0.174</td>
</tr>
</tbody>
</table>
Composite Barrier Calculations
Lamination of n Layers

\[ \frac{1}{P_{\text{lam}}} = \left( \frac{X_1}{P_1} \right) + \left( \frac{X_2}{P_2} \right) + \ldots + \left( \frac{X_n}{P_n} \right) \]

Printed OPP/Metallized/EVA

<table>
<thead>
<tr>
<th>Material</th>
<th>TO2 (cc/100in²/day)</th>
<th>WVTR (gm/100in²/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPP</td>
<td>163</td>
<td>.45</td>
</tr>
<tr>
<td>Metallized</td>
<td>0.05</td>
<td>.05</td>
</tr>
<tr>
<td>Nylon/EVOH/Nylon</td>
<td>0.1</td>
<td>11</td>
</tr>
<tr>
<td>EVA</td>
<td>200</td>
<td>0.6</td>
</tr>
</tbody>
</table>

\[
\frac{1}{P_{T_{QA}}} = \frac{1}{163} + \frac{1}{0.05} + \frac{1}{200} \quad + = \quad 0.0064 + 0.45 + 0.0052 = 0.4619
\]

\[
P_{T_{QA}} = 0.4619 \quad \text{or} \quad 0.4990.5
\]

\[
\frac{1}{P_{WVT_{R}}} = \frac{1}{45} + \frac{1}{0.5} + \frac{1}{6} = 2.22 + 20 + 1.67 = 23.89
\]

\[
P_{WVT_{R}} = 0.042
\]
Barrier Mapping


WVTR vs. OTR for various Barrier Films

- Al Foil
- MET-UHB
- MET-HB
- 70MET / 60MAC
- MET PET
- Al/amPA/OPP
- Al/APET/OPP
- SiO2/PET
- SiO2/OPP
Metal Adhesion Specification

At Metallization

- No pin windows on unwinding
- No pick off 610 tape
- Threshold strength on heat sealing adhesion test (gm/in – kg/cm)
  - Tie to lamination performance by testing

At end user

- No metal transfer on delamination
- Specific peel strength value
  - Related to lamination method
  - Related to lamination performance???
Web Handling System

- Rewinder in vacuum
- Driven and idler rolls
  - Individual rolls driven; Digital drive
  - Chain or belt driven
- Three tension zones
  - Unwind break
  - Chill roll
  - Rewind with various control methods
Key Substrate Properties: Winding and web transport

- MD Modulus
- Yield Strength
- Yield Point
- Film Thickness / Web width
- Shrinkage; % and Temperature
- Coefficient of Friction
- Metallization Surface
Poisson’s Ratio:
source of MD wrinkles and “Railroad Tracks”

\[ \varepsilon_x = \frac{L_1 - L}{L_0}, \text{ axial strain} \]
\[ \varepsilon_y = \frac{W_1 - W}{W_0}, \text{ lateral strain} \]
\[ \varepsilon_z = \frac{t_1 - t}{t_0}, \text{ compressive strain} \]

Poisson's Ratio \( \frac{-\varepsilon_y}{\varepsilon_x} \)

\( \nu \approx 0.3 \) for most polymers
Lateral Compressive Wrinkles

- As web heat up or as tension is reduced the web grows in width.
- As web spreads it is resisted by friction between roll surface.
- If the frictional force exceeds the buckling force the web will wrinkle (pushes in on web edges).
- Wrinkles are in the MD and generally evenly spaced.

COF also impacts

Railroad track (Tram line)
Film Tensile Property Comparison

Fig. 3  Stress-strain curves for several polymer films.
Film Strength Comparison

- **PET**: 180%, 37.5
- **PAPER**: 3%, 22.9
- **OPP**: 232%, 14.6
Maximum Web Tension

- Determine PLI (pounds per inch) for 10% of Elastic limit of a 60 inch wide 1 mil product

- Paper 3% @ 22900 psi = 137.4 lbs = 2.3 pli
- PET 5% @ 32000 psi = 192.0 lbs = 3.2 pli
- OPP 33% @ 18000 psi = 108.0 lbs = 1.8 pli

- Cross sectional Area = 60 in * 0.001 in = 0.06 in²
- Load/cross-sectional area = 0.1 * Yield Stress
Winding Tension Level

• Tension level should keep MD elongation below 1% elongation
• Must have good tensile data at low elongation
• Calculate just like web handling example but at 1% elongation as opposed to 10% elongation
Conclusions

- Film specifications multifaceted
  - End use dependent
  - Equipment dependent
- Must know the FFU
- Generate Substitute Quality Characteristics
- Characterize film property performance for each Metallizing Chamber
Appendix
Source of Metallized Film Barrier

- Aluminum is necessary but not sufficient
- The surface on which the metal is deposited controls the oxygen and moisture barrier
- The substrate controls the balance between:
  - Moisture
  - Oxygen
  - Aroma
- Surface Free energy of the surface impacts metal "quality"
## Typical PET Product Designs

<table>
<thead>
<tr>
<th>Aluminum layer</th>
<th>Plane film</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homopolymer PET</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Aluminum layer</th>
<th>Sealed Film</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homopolymer PET</td>
<td></td>
</tr>
<tr>
<td>Sealable polymer layer</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Aluminum layer</th>
<th>High Barrier PET</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEN polymer surface</td>
<td></td>
</tr>
<tr>
<td>Homopolymer PET Core</td>
<td></td>
</tr>
</tbody>
</table>
## Typical OPP Product Design

<table>
<thead>
<tr>
<th>Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aluminum layer</strong></td>
</tr>
<tr>
<td>Treated EP-copolymer surface</td>
</tr>
<tr>
<td><strong>Homopolymer PP Core</strong></td>
</tr>
<tr>
<td><strong>Sealable polymer layer</strong></td>
</tr>
</tbody>
</table>
## High Barrier Metallized OPP Product Design Concept

<table>
<thead>
<tr>
<th>Aluminum layer</th>
<th>EVOH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treated, Non OPP polymer surface</td>
<td>HDPE</td>
</tr>
<tr>
<td><strong>Homopolymer PP Core</strong></td>
<td>Amorphous NYLON</td>
</tr>
<tr>
<td></td>
<td>Amorphous PET</td>
</tr>
</tbody>
</table>
## Barrier Property Summary

<table>
<thead>
<tr>
<th>SUBSTRATE</th>
<th>Coating</th>
<th>WVTR ** Gm/M²/24 hr</th>
<th>Oxygen permeability *** CC/M²/24 hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET*</td>
<td>Al</td>
<td>0.93</td>
<td>1.24</td>
</tr>
<tr>
<td>BOPP*</td>
<td>Al</td>
<td>1.24</td>
<td>54.2</td>
</tr>
<tr>
<td>BON*</td>
<td>Al</td>
<td>1.24</td>
<td>1.5</td>
</tr>
<tr>
<td>LDPE*</td>
<td>Al</td>
<td>1.50</td>
<td>310.0</td>
</tr>
<tr>
<td>OPP/Copolymer</td>
<td>Al</td>
<td>0.93</td>
<td>60.0</td>
</tr>
<tr>
<td>OPP/AmPA</td>
<td>Al</td>
<td>1.20</td>
<td>3.1</td>
</tr>
<tr>
<td>OPP/APET</td>
<td>Al</td>
<td>0.78</td>
<td>5.6</td>
</tr>
<tr>
<td>OPP/EVOH</td>
<td>Al</td>
<td>0.16</td>
<td>0.3</td>
</tr>
<tr>
<td>EVOH/OPP</td>
<td>Al</td>
<td>1.93</td>
<td>61.9</td>
</tr>
<tr>
<td>PET</td>
<td>SiO₂</td>
<td>1-10</td>
<td>1-2</td>
</tr>
<tr>
<td>Special OPP</td>
<td>SiO₂</td>
<td>1-2</td>
<td>1-2</td>
</tr>
</tbody>
</table>


**WVTR: ASTM test method F1249-90, 37.8 °C (100 °F) and 90% relative humidity (RH).

***Oxygen permeability: ASTM test method D 3985-81, 23 °C (73.4 °F) and 0% RH.
The figure shows the film modulus for various types of films, represented in GPa (Giga Pascals). The modulus values are depicted as minimum and maximum ranges. The film types include Cellophane, Cellulose Acetate, Nylon-6, Polycarbonate, HDPE, LDPE, ionomer, polyethylene terephthalate (PET), polyethylene, polypropylene, polystyrene, nonrigid PVC, Saran (DOW trademark), and others.

- **Cellophane**
  - Minimum: 3.1 GPa
  - Maximum: 3.1 GPa

- **Cellulose Acetate**
  - Minimum: 2.4 GPa
  - Maximum: 2.4 GPa

- **Nylon-6**
  - Minimum: 0.6 GPa
  - Maximum: 0.6 GPa

- **Polycarbonate**
  - Minimum: 2.5 GPa
  - Maximum: 2.5 GPa

- **HDPE**
  - Minimum: 1.0 GPa
  - Maximum: 1.0 GPa

- **LDPE**
  - Minimum: 0.1 GPa
  - Maximum: 0.1 GPa

- **Ionomer**
  - Minimum: 0.4 GPa
  - Maximum: 0.4 GPa

- **Polyethylene terephthalate (PET)**
  - Minimum: 0.15 GPa
  - Maximum: 0.15 GPa

- **Polyethylene**
  - Minimum: 2.5 GPa
  - Maximum: 2.5 GPa

- **Polypropylene**
  - Minimum: 5.5 GPa
  - Maximum: 5.5 GPa

- **Polystyrene**
  - Minimum: 3.1 GPa
  - Maximum: 3.1 GPa

- **Nonrigid PVC**
  - Minimum: 2.7 GPa
  - Maximum: 2.7 GPa

- **Saran (DOW trademark)**
  - Minimum: 1.1 GPa
  - Maximum: 1.2 GPa
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- Polymer Processing and Troubleshooting
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- Viscosity measurements
- Extrusion and Melt System
  Design, Specification and Start-Up
- Polymer Film Design and Manufacture
- Microscopic Film evaluation and layer thickness measurement
- Film Surface Treatment
- Metallization of Polymer Films
- Customized In-House Training Classes
- Expert Witness and Intellectual Property Specialist
- Literature Searches and Technology Reviews

- QUALITY SERVICE
- Confidentiality
  Complete confidentiality of client information with no disclosure of confidential information
- Ethical
  All patentable concepts developed while working for client, disclosed and assigned to client,
- Efficiency
  A knack for being able to “zero-in” on the problem at hand and to systematically identify solutions,
- Team Player/Excellent Communicator
  Able to work well with line-operators, engineering staff and management to cross-communicate technical information,
- LIFETIME EXPERIENCE/ TOP-NOTCH KNOWLEDGE
  Troubleshoot or focus your R & D having the advantage of a lifetime of learning and experience,
- Continuous Improvement
  Goal is to exceed the client’s expectations and to provide information about the most recent advancements in the field,
- References
  Professional references gladly provided.