Nichigo G-Polymer®
Biodegradable, High Barrier, Water Soluble, Extrusion Polymer

Presented by:
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Commercial Development Manager
Soarus LLC
Agenda

1. Soarus Overview
2. What is the New Polymer?
3. Biodegradable, Compostable
4. Barrier Properties
5. Extrusion
6. Water Solubility
7. Conclusions
Soarus LLC is a subsidiary of Nippon Gohsei and the exclusive representative for Nippon Gohsei’s Soarnol® EVOH (ethylene vinyl alcohol copolymer) in North America; together with a sister company providing tie layer adhesives and peelable sealants serves the barrier coextrusion industry.
Biodegradable Trend

- Structure resins PLA, PHA
- No current biodegradable / compostable high barrier coextrusion resin
- Now HAVOHOH polymer, highly amorphous vinyl alcohol polymer
G?
= Green
i.e. biodegradable, naturally compostable

HAVOH is the *first* biodegradable, *high barrier*, water soluble, highly *amorphous extrusion* polymer
What is HAVOH?

A highly amorphous vinyl alcohol polymer

- Biodegradable, Naturally Compostable
- Outstanding gas barrier @ < 65% RH (dry 200X EVOH oxygen barrier)
- Water soluble at room temperature
- Non-foaming when dissolved in water
- Extrudable with wide temperature processing window
- Polymer composition design flexibility to meet specific needs (MFR, MW, %C, C size, FV, MP, Solubility)
What is **HAVOH**?

**Highly Amorphous Vinyl Alcohol Polymer**

**Amorphous content**

- Clarity
- Stretch
- Solubility
- Extrusion

**HAVOH**

- Highest barrier
- Excellent extrudability
- Excellent water solubility
- Biodegradable, Compostable

**EVOH**

- Barrier
- Not extrudable
- Limited water solubility
- Biodegradable

**PVOH**

Hydrogen Bonding
Highly amorphous with attributes from PVOH and EVOH:

**PVOH**
- Water solubility
- Gas barrier
- Oil & solvent resist
- Dispersion

**EVOH**
- Extrusion
- Gas barrier
- Oil & solvent resist

**HAVOH**
- High amorphous
- High gas barrier
- Oil & Solvent resist
- Extrusion
- Transparency
- Water solubility
## Crystalline vs. Amorphous

<table>
<thead>
<tr>
<th>Property</th>
<th>Crystalline</th>
<th>Amorphous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intermolecular</td>
<td><em>Strong</em></td>
<td>Weak</td>
</tr>
<tr>
<td>Gas barrier</td>
<td><em>Better</em></td>
<td>---</td>
</tr>
<tr>
<td>Extrusion</td>
<td>---</td>
<td><em>Better</em></td>
</tr>
<tr>
<td>Orientation</td>
<td>---</td>
<td><em>Better</em></td>
</tr>
<tr>
<td>Mechanical</td>
<td><em>Better</em></td>
<td>---</td>
</tr>
<tr>
<td>Transparency</td>
<td>---</td>
<td><em>Better</em></td>
</tr>
<tr>
<td>Dimension control</td>
<td><em>Difficult</em></td>
<td><em>Easy</em></td>
</tr>
<tr>
<td>Chemical resist</td>
<td><em>Better</em></td>
<td>---</td>
</tr>
<tr>
<td>Water solubility</td>
<td>---</td>
<td><em>Better</em></td>
</tr>
</tbody>
</table>
Characteristics of HAVOH
Characteristics of **HAVOH**

**Excellent Water solution behavior for easy handling**
- Water solubility
- Less foaming
- Stable viscosity
- High speed coating

**Excellent Rheology for Extrudability**
- Low melting temp
- Melt tension
- Extrusion
- Orientation
- Transparency

**Excellent Dispersion, Emulsifiability**
- Protective colloid for acrylic monomers
- Dispersion for inorganics

**Excellent Barrier, Environmentally Friendly**
- Excellent Gas barrier
- Biodegradable, Compostable
HAVOH Properties

- Biodegradable, Compostable
- High Barrier
- Water Soluble
- Melt Extrusion
Biodegradable
Compostable
HAVOH has the same biodegradability as PVOH.

**[Test Method]**

- JIS K6950.
  
  Closed system oxygen consumption measuring apparatus Clonemeter OM3100
  
  Return sludge of the Ogaki factory  90mg/l.
  
  Loadings of a sample: 600ml
  
  Standard-testing solution: 300ml
  
  Temperature: 25±1 °C
  
  Exam time: For 70 days
Barrier Properties
### Oxygen gas barrier property

Temperature: 20 degree C, dry

<table>
<thead>
<tr>
<th>Material</th>
<th>cc.20um/m2.day</th>
<th>Normalized with HAVOH</th>
</tr>
</thead>
<tbody>
<tr>
<td>HAVOH</td>
<td>0.0023</td>
<td>1</td>
</tr>
<tr>
<td>PVOH</td>
<td>0.0050</td>
<td>2</td>
</tr>
<tr>
<td>EVOH</td>
<td>0.42</td>
<td>200</td>
</tr>
<tr>
<td>Nylon 6</td>
<td>76</td>
<td>35,000</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>3900</td>
<td>1,700,000</td>
</tr>
</tbody>
</table>

HAVOH gives 200 times better oxygen gas barrier property than EVOH under dry conditions.
HAVOH has the highest barrier property under 60%RH compared to any thermoplastic.

29-EVOH: Ethylene content 29mol%
44-EVOH: Ethylene content 44mol%
Film sample: Solution coating film
Oxygen Gas Barrier Property

HAVOH in a coextruded structure

• Oxygen barrier property of HAVOH is decreased under high humidity; therefore, HAVOH layer should be kept at lower humidity condition for best barrier performance.

• The layer of HAVOH should be located on the lower humidity side of a multi-layer structure.

Cross section of multi-layer structure

Higher gas barrier at lower humidity
HAVOH has high hydrogen gas barrier that can be used for next generation fuel systems.

Test Temperature
HAVOH: 41 degree C
EVOH: 41 degree C
Nylon resin: room temperature

H2 permeability (cc/20um/m2.day.atm)
Hydrogen Resistance

• Exposure test condition for hydrogen resistance
  – Temperature: 23 °C
  – Evaluation: Mechanical property
    Tensile test (test speed: 50mm/min)
  – Test piece: ISO527-3 type5, Thickness: 1mm
  – Exposure period: 300 hours

<table>
<thead>
<tr>
<th></th>
<th>Elastic Modulus</th>
<th>Tensile strength</th>
<th>Breaking elongation</th>
<th>Breaking stress</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MPa</td>
<td>MPa</td>
<td>mm</td>
<td>MPa</td>
</tr>
<tr>
<td>HAVOH</td>
<td>Before</td>
<td>5,500</td>
<td>150</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>5,500</td>
<td>155</td>
<td>5</td>
</tr>
</tbody>
</table>

HAVOH did not show changes in mechanical properties after exposure to hydrogen
Melt Extrusion
HAVOH can be easily melt extruded:

- **Multi-layer structures** can be produced by coextrusion.
- Conventional adhesive tie resins typically used with EVOH can be used.
- Coextrusions have **high barrier properties**.
- Coextrusions have good **formability**.
Thermal Stability for Extrusion

Difference between melting point and decomposition temperature of HAVOH is much wider than PVOH. HAVOH can be extruded with a wide processing window. PVOH cannot be extruded because PVOH’s decomposition temperature is close to the melting temperature.

<table>
<thead>
<tr>
<th></th>
<th>Melting point</th>
<th>Decomposition temp.</th>
<th>Wide processing window</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVOH</td>
<td>Tm=227 degree C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HAVOH</td>
<td>Tm=140 – 190 degree C</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Properties of HAVOH

<table>
<thead>
<tr>
<th></th>
<th>Tm °C</th>
<th>Tg °C</th>
<th>Crystallinity %</th>
</tr>
</thead>
<tbody>
<tr>
<td>HAVOH</td>
<td>140-190 (284-373F)</td>
<td>80 (176F)</td>
<td>0 – 20</td>
</tr>
<tr>
<td>PVOH</td>
<td>227 (441F)</td>
<td>72 (162F)</td>
<td>48</td>
</tr>
</tbody>
</table>
Properties of HAVOH for Extrusion

- Molecular Weight 20,000
- Crystallinity: Low (< 20%)
- Melt point 185°C
- MFR 5.0 g/10 min @ 210°C
- OTR 0.0023 cc.20um/m².day, 20°C, dry
- Biodegradable, Compostable
Processing conditions

Conventional extruder and screw for processing HAVOH

- (a) L/D of Extruder: 24 – 30
- (b) Screw Design: Full-flight type is recommendable

Avoid long feed sections which can trap air

Compression Ratio: 3.0 – 3.5
The recommended melt temperature is 190 - 210 degree C.
Processability - Melt viscosity

Melt viscosity depends on apparent shear rate of HAVOH. Similar viscosity versus shear profile to EVOH.
Processability, Coextrusion

• Multi-layer structures with HAVOH
  – can be co-extruded with polyolefin using standard coextrudable adhesive resins.

【Adhesive strength】

Test sample
Multilayer blown film

<table>
<thead>
<tr>
<th>LLDPE / Adhesive resin / HAVOH / Adhesive resin / LLD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness: 80 / 15 / 30 / 15 / 80 um</td>
</tr>
</tbody>
</table>

Test method
T peel (15mm width)
Peel speed: 100mm/s

*LLDPE based adhesive resin for EVOH, Ny

<table>
<thead>
<tr>
<th>Tie resin*</th>
<th>Adhesive strength (N/15mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>15</td>
</tr>
<tr>
<td>B</td>
<td>16</td>
</tr>
</tbody>
</table>
HAVOH gives lower yield point stress and can be easily oriented.
HAVOH has higher melt tension vs PVOH (low saponification and plasticized) allowing stable high velocity melt spinning.
Transparency

Haze (%)

HAVOH  Polypropylene

0  20  40  60  80  100

HAVOH  Polypropylene
Regulatory

- FDA compliance indirect food contact, 21CFR175.105
  (FDA Indirect: LDPE, LLDPE, EVA, PS G-Polymer; FDA Indirect: PET, HDPE, PP G-Polymer; Direct edge contact layer in PLA structures is underway)

- REACH Registered

Water Solubility
Water Solution Opportunities with HAVOH

- Water solution laminate a barrier layer
- High speed solution coating
- Excellent cold water solubility
- No foaming
Water solution behavior

HAVOH and PVOH

Increasing Temp: 30°C to 80°C (10°C/ min)
Solid content: 6%
Stable Viscosity of Water Solution

At room temp for 90 days

PVOH

HAVOH

HAVOH has low crystallinity for resistance to gel formation
Water solution behavior

- Less foaming property
HAVOH did not exhibit crystallization under high shear; suitable for high speed coating.
Water solution behavior

Control of crystallization just after 10 minutes stirring

HAVOH

PVOH

10% solution
Temperature: 10degreeC
Torque: 1000rpm
Dissolving HAVOH in Water

Non-woven Fabric

Dissolution test: Immersed in 20 degree C water

1 sec.

3 sec.

7 sec.
Dissolving HAVOH in Water

2 mil film:

Dissolution test: Immersed in 20 degree C water
Viscosity of Aqueous Solutions
Viscosity of aqueous solution (OKS-8049)

Concentration (%) vs. Viscosity (mPa.s)

- 20 deg. C
- 40 deg. C
- 60 deg. C

Graph showing the relationship between concentration and viscosity at different temperatures.
Viscosity of aqueous solution (OKS-8049)

Viscosity (mPa.s) vs Temperature (°C)

- 4%
- 8%
- 15%
- 20%
- 30%
Conclusions
Conclusions: New HAVOH
Highly Amorphous Vinyl Alcohol

• Biodegradable, Naturally Compostable
• Good melt extrusion thermal stability
• Excellent high barrier properties
• Good orientability
• High transparency
• Water-soluble
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Additional information is available on the website:

http://www.g-polymer.com/
Thank you

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Please remember to turn in your evaluation sheet...