Polyethylene Coextruded Blown Film: Layer Arrangement and Gloss

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ABSTRACT

A study was conducted to evaluate the effect of layer arrangement on the gloss of coextruded polyethylene blown films. Part 1 of this work examines the widely accepted preference for 45-degree gloss measurement within the plastic films industry by testing a series of polyethylene coextruded films at multiple angles of incidence, namely 20°, 45°, 60° and 85°. This research reveals that gloss-20 has the greatest sensitivity to change in coextruded film structure, gloss-45 and gloss-60 show good resolution between polyethylene films, gloss-60 provides the highest absolute values (with the exception of the low gloss film), and gloss-85 is ill-suited for providing resolution between samples. It also concludes that gloss-45 is a suitable choice for providing resolution between polyethylene blown films.

Part 2 of this paper explores the contribution to gloss-45 through varying the layer arrangement and layer composition in coextruded blown films. It is repeatedly demonstrated in this body of work that adding a high gloss polyethylene resin to a low gloss film has the ability to yield high overall gloss values. Furthermore, it is shown that a coextruded film with A/B/A construction has a higher gloss-45 value than an A/A/A film.

INTRODUCTION

In today’s competitive but burgeoning flexible packaging industry, designers are spending a significant amount of time and resources understanding how to best obtain consumer attention with package appearance alone. Package sparkle and shine have become as important in packaging appearance as print and graphic quality. This is especially true in food packaging markets where pouches of all shape and sizes are vying for consumer attention, and coextruded or laminated flexible structures are continuously replacing traditional materials like glass, paper and metal containers.

Polyethylene is a versatile polymer receiving increased recognition for use in these complex packaging structures. Polyethylene performs exceptionally well in coextruded and laminated films where it contributes to properties such as toughness, heat-seal and opticals among others. Optical properties such as gloss, haze and clarity are industry standard measurements and are often examined in combination. For the purpose of this paper, gloss was selected as the topic of focus.

Perhaps the most suitable way to evaluate the sparkle of a package is through the use of a controlled human perception panel. At the time of issuing this report, the authors were unable to locate published data testing this belief. There are a number of challenges associated with a viewing panel, which may be why no study has yet been found. Challenges include appropriate package display (e.g. film vs. formed package, empty vs. full), influence of lighting (e.g. direct vs. diffuse), mood and eyesight of panel individuals, and the use of appropriate descriptors (e.g. see-through appearance vs. surface sparkle).

In the absence of human panel feedback, package and film designers are left to rely on the available, more simplified physical measurements. There is a commonly held belief that a high gloss film when used to package consumer goods correlates to high package sparkle when placed on the display shelf. This in turn provides a visually attractive and differentiated product that the consumer is more apt to buy.

The glossy appearance of a film is a result of light reflecting from its surfaces. Gloss is quantifiable by methods which measure the intensity of a reflected beam of light (in the mirror direction) under well
defined conditions (e.g. ASTM 2457). Literature states that the intensity of the specularly reflected beam is influenced by the film refractive index, the surface roughness, and the angle of incidence. Gloss measured with a 45° angle of incidence is widely accepted by the plastic film industry. Part 1 of this paper examines this convention by evaluating a series of polyethylene coextruded films using gloss measured at multiple angles of incidence, namely 20°, 45°, 60° and 85°.

Gloss is closely associated with the surface roughness of a film simply because the intensity of a reflected beam of light depends largely on the surface upon which reflection occurs. This is well documented in published literature (1, 2, 3). Gloss is also closely associated with the refractive index of the material itself because light directed at the surface has the potential to be refracted and transmitted through the film. Because the range of refractive indices for polyethylene materials is considered small (1.51 to 1.54), differences in refractive index are usually neglected (1). In Part 2 of this paper an examination is made of the internal contribution of gloss-45 in multi-layer polyethylene coextruded films.

EXPERIMENTAL

Films produced in both Part 1 and Part 2 of this study were made using a Brampton Engineering coextrusion air-cooled blown film line. This line is equipped with three individual extruders providing an A/B/C configuration. The extruders are fed to a 4-inch diameter, pancake modular streamlined coextrusion die. Each extruder is fitted with a conventional flight screw with mixing section, 45-mm (1¾-inch) root diameter and 30:1 L/D. All films were made under the same run conditions at 45 kg/h output rate (8 lb/h/inch-circ), 0.89-mm (35-mil) die gap, 51-micron (2.0-mil) film gauge and 2.5:1 blow-up ratio. The resins used in Part 1 and Part 2 of this study are manufactured by NOVA Chemicals Corporation and are summarized the Table I below.

<table>
<thead>
<tr>
<th>Resin</th>
<th>Melt Index g/10min</th>
<th>Density g/cc</th>
<th>Mn (kg/mol)</th>
<th>Mw (kg/mol)</th>
<th>PolyDispersity</th>
<th>Denotation</th>
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</thead>
<tbody>
<tr>
<td>SURPASS® HPs900-C</td>
<td>1.0</td>
<td>0.917</td>
<td>32</td>
<td>102</td>
<td>3.19</td>
<td>sLL</td>
</tr>
<tr>
<td>SCLAIR® 19C</td>
<td>0.95</td>
<td>0.958</td>
<td>34</td>
<td>118</td>
<td>3.44</td>
<td>HD</td>
</tr>
<tr>
<td>Experimental octene-LLDPE</td>
<td>1.0</td>
<td>0.922</td>
<td>28</td>
<td>99</td>
<td>3.55</td>
<td>exp-LL</td>
</tr>
</tbody>
</table>

Resin sLL is a single-site catalysed octene-ethylene copolymer LLDPE resin manufactured using solution-phase Advanced SCLAIRTECH™ technology (hereafter referred to a S-technology). Resin HD is a homopolymer, medium molecular weight, high density polyethylene resin manufactured using solution-phase S-technology. Both resins are formulated with polymer processing aid additive. These resins were selected for this study because their respective blown films have greatly differing gloss properties, where the former is high gloss and the latter is matte. The difference in gloss is not unexpected given the molecular architecture differences between a homopolymer high density polyethylene resin and an octene-ethylene copolymerized linear low density polyethylene resin with a significantly lower density.

The experimental octene-LLDPE resin was also selected because it has a density which is similar to the sLL sample, but with inferior optical properties. It is incorporated later in the study as a replacement resin to HD.

The 3-layer coextruded blown films made in Part 1 of the study are summarized in Table II. Resins were present at 100% concentration in each of their respective layers. The coextruded blown films made in Part 2 of the study are summarized in Table III. These films were made with a layer percentage of 33/34/33, and all resins were present at 100% concentration in each layer; that is, no blending was performed.
PART 1. MULTI-ANGLE GLOSS MEASUREMENT OF COEXTRUDED BLOWN FILMS

The objective of this study was to evaluate and compare gloss measurements obtained with multiple angles of incidence on a series of coextruded polyethylene films which vary in composition.

The standard angles of incidence found in commercially available reflectometers (gloss meters) are 20°, 45°, 60° and 85°. Within these instruments, a collimated white light is directed at the specimen surface at the prescribed angle measured from normal (Figure 1). A photoelectric detector with a defined receptor window is positioned at the angle of mirror reflection. The intensity of specular light reflected from the surface to the detector is measured. The remaining light is either reflected at angles outside the detector window or is refracted and transmitted through the sample. The intensity of the reflected specular light is related to that of a highly polished black glass standard with a defined refractive index, typically 1.567. The standard is assigned a specular gloss value of 100 for each geometry. Black glass is used as a standard because it reflects light in the direction of mirror reflection (the specular gloss) and it acts as a light trap so there is no reflection from a secondary surface.

Different geometries are better suited for measuring certain surfaces. It is necessary to choose the correct geometry to guarantee high measurement accuracy. Geometry is often distinguished according to the field of application. For example, standard angles of illumination for the paint and coatings industry are 20°
(gloss-20, high gloss), 60° (gloss-60, medium gloss) and 85° (gloss-85, low gloss). There are also specialty industry angles such as 45° for the ceramic and plastic film industries and 75° for the paper and vinyl industries.

BYK-Gardner provides a good illustration on the importance of selecting the proper gloss geometry (4). A test was performed where thirteen black glass tiles were ranked from matte to high gloss, and measured with 20°, 60° and 85° gloss geometries. The specular gloss was assigned a value of, or close to, 100 for each geometry. The results are captured in Figure 2. The data show that gloss-85 provides poor resolution between the high gloss glass tiles and it provides the best resolution between low gloss tiles. Gloss-20 is better suited for the high gloss tiles.

Figure 2. Series of Black Glass Tiles with Increasing Gloss Measured at Multiple-Angles (Data from Reference 4.)

![Figure 2](image)

PART 1. RESULTS

The multi-angle gloss results for Part 1 of this study are found in Table IV and Figure 3. For all angles, the sLL/sLL/sLL film has a greater gloss value than the HD/HD/HD film. This delta is most pronounced for gloss-20 and least pronounced for gloss-85. For gloss-45, the sLL/sLL/sLL film has a gloss value 2.5 times greater than the HD/HD/HD film.

Table IV. Multi-Angle Gloss Results

<table>
<thead>
<tr>
<th>Sample</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside Layer</td>
<td>HD</td>
<td>sLL</td>
<td>sLL</td>
<td>sLL</td>
</tr>
<tr>
<td>Core Layer</td>
<td>HD</td>
<td>sLL</td>
<td>HD</td>
<td>HD</td>
</tr>
<tr>
<td>Inside Layer</td>
<td>HD</td>
<td>sLL</td>
<td>HD</td>
<td>HD</td>
</tr>
<tr>
<td>Layer Percentages (outside/core/inside)</td>
<td>33/34/33</td>
<td>33/34/33</td>
<td>30/50/20</td>
<td>15/50/35</td>
</tr>
<tr>
<td>GLOSS 20</td>
<td>11</td>
<td>75</td>
<td>62</td>
<td>64</td>
</tr>
<tr>
<td>GLOSS 45</td>
<td>27</td>
<td>69</td>
<td>57</td>
<td>58</td>
</tr>
<tr>
<td>GLOSS 60</td>
<td>58</td>
<td>115</td>
<td>96</td>
<td>99</td>
</tr>
<tr>
<td>GLOSS 85</td>
<td>95</td>
<td>105</td>
<td>100</td>
<td>101</td>
</tr>
</tbody>
</table>

The gloss-85 curve across all films is relatively flat and does not provide much resolution between samples. These results are consistent with the previous illustration which shows gloss-85 is not well suited for high gloss surfaces (Figure 2). Gloss-20 and gloss-45 both show a significant difference between Samples A and B. The gloss-60 values are shifted upwards although the relative difference between films remains the
same. Gloss-60 for the sLL/sLL/sLL film exceeds 100 gloss units indicating that light is being reflected from the secondary surface layer, that is, from the film inside surface.

Figure 3. Multi-Angle Gloss Results

In an effort to improve the gloss value for the HD/HD/HD film, the outside surface layer was replaced with sLL (Sample C). It is recognized that the layer percentages were not held constant for these films however the difference is minor and not believed to have a significant impact on measured gloss. The change in skin layer was successful at increasing gloss across all angles. The increase was most dramatic with gloss-20 where an increase from 11 to 62 gloss units was observed. For gloss-45 the increase was also significant, with a change from 27 to 57. While the gloss value of the modified film increased it did not, however, reach that of the sLL/sLL/sLL film. This held true for all measured angles, suggesting other factors beyond skin layer surface effects are at play in determining the final gloss value. These factors are further explored in Part 2 of this paper.

As a final step, the outside sLL skin layer thickness was reduced in half (Sample D) while maintaining the overall gauge constant. This appears to have had no significant impact to gloss (at any angle) suggesting that there is opportunity to optimize the skin layer thickness while achieving sufficient overall gloss.

In summary, for the films considered in Part 1, gloss-20 has the greatest sensitivity to change in coextruded film structures, gloss-45 and gloss-60 show good resolution between films, gloss-60 provides the highest absolute values, and gloss-85 is ill-suited for providing resolution between samples. Gloss-45 is a suitable choice for providing resolution between polyethylene blown films.

PART 2. THE EFFECT OF COEXTRUDED FILM LAYER ARRANGEMENT ON GLOSS

The objective of this study was to evaluate the effect of layer arrangement on gloss-45 of coextruded polyethylene blown films.
PART 2. RESULTS

In Part 1, gloss-45 was found to be dramatically different for the sLL/sLL/sLL and HD/HD/HD films. Gloss also improved significantly for the HD/HD/HD film when the outside skin layer was replaced with sLL. Both of these observations were repeated in Part 2.

As shown in Table V and Figure 4, the sLL/sLL/sLL film had a gloss-45 value three times greater than the HD/HD/HD film. With the skin layer change, gloss-45 increased substantially from 21 to 52. Here again, however, while gloss-45 improved, it did not reach that of the sLL/sLL/sLL film.

Table V. Gloss-45 Results for Part 2

<table>
<thead>
<tr>
<th>Sample</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
<th>L</th>
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<tbody>
<tr>
<td>Outside Layer</td>
<td>sLL</td>
<td>HD</td>
<td>sLL</td>
<td>sLL</td>
<td>sLL</td>
<td>HD</td>
<td>HD</td>
<td>HD</td>
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<td>Core Layer</td>
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<td>HD</td>
<td>sLL</td>
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<td>Inside Layer</td>
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<td>sLL</td>
<td>sLL</td>
<td>HD</td>
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<tr>
<td>GLOSS 45</td>
<td>62</td>
<td>21</td>
<td>52</td>
<td>60</td>
<td>74</td>
<td>62</td>
<td>44</td>
<td>25</td>
</tr>
</tbody>
</table>

Figure 4. Gloss-45 Results for Part 2

Additional benefit to gloss was realized when the core layer of the 3-layer coextruded film structure was replaced with sLL (Sample H). When both skin layers were replaced with sLL (while maintaining HD in the core layer), an expected result was obtained. The gloss-45 value for the sLL/HD/sLL film exceeded that of the sLL/sLL/sLL film (by 19%). It appears that by placing sLL in both skins an optimum condition for gloss was met. Similarly the HD/sLL/HD film had a higher gloss value than the HD/HD/HD film although the effect was not as pronounced.

To further verify the reproducibility of these findings, another series of films were produced. In this case an experimental octene-LLDPE resin was used in place of HD. This resin has a density which is fairly similar to the sLL sample, but with inferior optical properties. These results are reported in Table VI and Figure 5.

Table VI. Gloss-45 Results for Part 2 with experimental octene-LLDPE (exp-LL) in place of HD

<table>
<thead>
<tr>
<th>Sample</th>
<th>M</th>
<th>N</th>
<th>O</th>
<th>P</th>
<th>Q</th>
<th>R</th>
<th>S</th>
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</thead>
<tbody>
<tr>
<td>Outside Layer</td>
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<td>sLL</td>
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<td>exp-LL</td>
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<tr>
<td>Core Layer</td>
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<td>exp-LL</td>
<td>sLL</td>
<td>exp-LL</td>
<td>sLL</td>
<td>exp-LL</td>
<td>sLL</td>
</tr>
<tr>
<td>Inside Layer</td>
<td>exp-LL</td>
<td>exp-LL</td>
<td>exp-LL</td>
<td>exp-LL</td>
<td>sLL</td>
<td>sLL</td>
<td>exp-LL</td>
</tr>
<tr>
<td>GLOSS 45</td>
<td>24</td>
<td>54</td>
<td>59</td>
<td>82</td>
<td>56</td>
<td>45</td>
<td>31</td>
</tr>
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</table>
The gloss-45 results were found to be similar to the HD films. The same optimized conditions appear to hold true when sLL is placed in both skin layers (with exp-LL in the core); that is, gloss-45 for sLL/exp-LL/sLL exceeds that of sLL/sLL/sLL (by 32%). These findings suggest the skin optimization effect is not limited to homopolymer resin.

Two possible explanations are provided for these findings.

**Theory 1.** Internal layer interfaces within the coextruded film structure have an impact on gloss-45. In other words, gloss is not strictly a surface phenomenon. When a new interface is introduced into the film, specifically an interface between two dissimilar materials, a new reflective surface is added. This new surface has the potential to reflect light back to the gloss detector.

The concept of additional reflective surfaces is further defined in Figure 6. Two additional reflective surfaces are introduced by changing the core layer polyethylene material to one of dissimilar refractive index from the skin layers.

**Figure 6. Reflection of incident light beam for similar and dissimilar core layers**
Theory 2. The roughness of the outside surface layer is solely responsible for gloss. This hypothesis is more consistent with existing literature as sighted above. Surface roughness of the outside layer varies as the velocity profile at the die exit changes. This velocity profile is known to depend on the distribution of the layers (5). Atomic Force Microscopy testing can be used to further validate this postulation, along with Numerical Multi-Layer Flow Analysis in the die.

CONCLUSIONS

The main findings of this research are summarized as follows:

− Gloss measured at an angle of 45° is appropriate for providing resolution between polyethylene blown films.
− Adding HPs900-C, a high gloss polyethylene resin, to the skin layer of a low gloss film will yield high gloss values. The thickness of the high gloss skin layer can be optimized to balance cost with overall glossy appearance.
− A coextruded film with A/B/A construction has a higher gloss-45 value than an A/A/A film.

Package sparkle can be optimized through the use of a high gloss resin in the outer skin layer of a coextruded film. Additional enhancement can be achieved by modifying the other coextrusion layers. This research demonstrates gloss is not strictly a surface effect and the internal layers of a coextruded film play a significant role in determining the overall glossy appearance of a film.

REFERENCES

Polyethylene Coextruded Blown Film: Layer Arrangement and Gloss

Presented by:
Kathleen McCormick

Outline
• Background
• Objectives
• Experimental
• Results and Conclusions
  ➢ Part 1. Multi-Angle Gloss Measurement
  ➢ Part 2. Gloss-45 of Multi-Layer Films
• Theories
• Final Remarks

Background
• Flexible packaging is a high growth industry
  ➢ Growth through replacement of traditional materials
• Increased importance on package sparkle and shine
• Lack of (published) human perception panel feedback
• Common belief that high gloss film correlates to high package sparkle
• What is gloss?
Background
• Gloss is...
  ➢ a result of light reflecting from film surfaces
  ➢ a simple, non-objective physical property
  ➢ an optical property (often considered in combination with haze and clarity)
  ➢ quantifiable by measuring the intensity of a reflective beam of light under well-defined conditions (ASTM 2457)
• Common angles of incidence or “geometries”:
  ➢ 20°, 45°, 60°, 85°

Background
• Common glossmeter geometries
  ➢ Gloss-45: a specialty angle for plastic film industry
  ➢ Gloss-20, -60 and -85: common in paint & coatings

Measurement of Black Glass Tiles with Increasing Gloss

Background

• Part 1 Objective:
   ➢ To examine the Gloss-45 convention by evaluating a series of polyethylene coextruded films using Gloss-20°, -45°, -60° and -85°

Background

• Gloss is influenced by
   ➢ Angle of incidence
   ➢ Surface roughness
   ➢ Film refractive index

Background

• Gloss is influenced by
   ➢ Angle of incidence
   ➢ Surface roughness
   ➢ Film refractive index
Background

- Gloss is influenced by
  - Angle of incidence
  - Surface roughness
  - Film refractive index

Well documented

- Often neglected

Part 2 Objective:
- To examine the internal contribution of Gloss-45 in PE co-extruded blown films
**Experimental**

- **Film blowing conditions:**
  - Brampton 3-layer co-extrusion film line
  - A/B/C configuration
  - 4-inch diameter, pancake modular streamlined die
  - 35-mil die gap, 2.5:1 blow-up ratio
  - 100 lb/h output (8 lb/h/in-circ)
  - 2.0-mil film gauge

- **Gloss tested in accordance with ASTM D2457**
  - using BYK-Gardner 45\(^{\circ}\) and 20\(^{\circ}/60^{\circ}/85^{\circ}\) Microgloss reflectometer units

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**Polyethylene Resins**

<table>
<thead>
<tr>
<th>Resin</th>
<th>Melt Index (dg/min)</th>
<th>Density (g/cm(^3))</th>
<th>Mn (kg/mol)</th>
<th>Mw (kg/mol)</th>
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<th>Denotation</th>
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<td>192</td>
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<tr>
<td>SCLAI R(^{\circ}) 19C</td>
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<td>34</td>
<td>116</td>
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<tr>
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<td>28</td>
<td>99</td>
<td>3.55</td>
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**Coextruded Films**

- **Part 1.**

<table>
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<tr>
<th>Sample</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
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<td>sLL</td>
<td>HD</td>
</tr>
<tr>
<td>Core Layer</td>
<td>HD</td>
<td>sLL</td>
<td>sLL</td>
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<tr>
<td>Inside Layer</td>
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</tr>
<tr>
<td>Layer Percentages</td>
<td>33/34/33</td>
<td>33/34/33</td>
<td>30/50/20</td>
<td>15/50/35</td>
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- **Part 2. All Films 33/34/33**

<table>
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<tr>
<th>Sample</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
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<td>Outside Layer</td>
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<td>Core Layer</td>
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Recap

• Part 1 Objective:
  ➢ To examine the Gloss-45 convention by evaluating a series of polyethylene coextruded films using Gloss-20°, -45°, -60° and -85°

• Part 2 Objective:
  ➢ To examine the internal contribution of Gloss-45 in PE co-extruded blown films

Part 1. Results

Multi-Angle Gloss Measurements on PE Coextruded Blown Film
2.0-mil gauge, outside layer measured

- Gloss 20°: greatest delta between sLL/sLL/sLL & HD/HD/HD (11 to 75)
- Gloss-45: sLL/sLL/sLL is 2.5 times greater than HD/HD/HD
- Gloss-60: provides highest absolute values (except for HD/HD/HD)
  ➢ sLL/sLL/sLL exceeds 100 gloss units indicating light is reflected from secondary surface
- Gloss-85: provides little resolution between samples
Part 1. Results

• Gloss increases when outside surface layer of HD/HD/HD film is replaced with sLL
  ➢ true for all geometries
  ➢ however gloss does not reach that of sLL/sLL/sLL
• Gloss is not impacted when outside sLL skin layer thickness is reduced by half (gauge held constant)

Part 1. Conclusions

• Gloss-45 is a suitable choice for providing resolution between PE blown films
• Adding a high gloss polyethylene resin to the outside skin layer of a low gloss film will yield high gloss values
• The thickness of the high gloss skin layer can be optimized to balance cost with overall glossy appearance

Part 2. Results

Gloss-45 Measurements on PE Coextruded Blown Film
2.0-mil gauge, outside layer measured, layer percentages 33/34/33
Part 2. Results

Gloss-45 Measurements on PE Coextruded Blown Film
2.0-mil gauge, multiple layer, measured layer percentages 33/34/33

Part 2. Main Conclusions

- Observations from Part 1 were repeated in Part 2
- Optimum condition for gloss is met by placing a high gloss resin in both skin layers with a dissimilar material in the core layer
  - sLL/HD/sLL gloss exceeds that of sLL/sLL/sLL
  - sLL/exp-LL/sLL gloss exceeds that of sLL/sLL/sLL
- The effect is also seen with the following films:
  - HD/sLL/HD gloss exceeds that of HD/HD/HD
  - exp-LL/sLL/exp-LL gloss exceeds that of exp-LL/exp-LL/exp-LL

Theories

- Theory 1. When a new interface is introduced into the film, specifically an interface between two dissimilar materials, a new reflective surface is added. This new surface has the potential to reflect light back to the gloss detector.
Theories

• Theory 2. The roughness of the outside surface layer is solely responsible for gloss. Surface roughness of the outside layer varies as the velocity profile at the die exit changes, and the velocity profile is known to depend on the distribution of the layers.

Final Remarks

• Gloss-45 is a suitable convention for the polyethylene plastic film industry
• Gloss can be optimized through the use of coextruded blown film structures
  ➢ by using a high gloss resin in outside skin layer
  ➢ by adjusting the high gloss skin layer thickness
  ➢ by using a high gloss resin in both skins with a dissimilar material in the core layer

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Please remember to turn in your evaluation sheet...