Visual and Instrumental Evaluation of Mottling and Striping

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Mottling / cloudiness of metallic coatings
Irregular areas of lightness variation

- undesirable defect at effect coatings
- especially noticeable on large body panels
- most obvious on light metallic finishes
Mottling / cloudiness of metallic coatings
Flake orientation

Parallel & uniformly distributed

Disorientation or varying hiding
Perception of Mottling
Depending on illumination, viewing angle, distance and size
Evaluation of Mottling
Which pattern size is perceived as mottle?

- Experts and non-experts mainly recognize mottle sizes between 50 to 100 mm. Extremes ranged from 25 to 200mm.
- Therefore, for visual inspection and measurement a min. sample area of about 300 x 500 mm is recommended.
How to measure Mottling
Scanning the mottle pattern

scanning 10 ...100 cm
Measurement
Optical principle

Illumination:
15° to perpendicular

Detection:
45°
60°

Spot size approx. 4x4 mm

Detection 15°
Specular reflection
Measurement
Minimize the influence of tilting

Sample surface

Illumination
15° to perpendicular

Specular reflection

Detection +15°

Detection -15°
Measurement
Minimize the influence of tilting

Illumination
15° to perpendicular

Detection
+15°

Specular reflection

Detection
-15°

Sample surface

Object curvature
radius > 500 mm
Measurement
Influence of tilting - Character Lines

-15°  15°  ±15°
45°  60°
Measurement
Cloud ranges

The signal is separated by mathematical filters:

<table>
<thead>
<tr>
<th>Mottle Size</th>
<th>min. scanlength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Md</td>
<td>6 - 13 mm</td>
</tr>
<tr>
<td>Me</td>
<td>11 - 24 mm</td>
</tr>
<tr>
<td>Mf</td>
<td>19 - 42 mm</td>
</tr>
<tr>
<td>Mg</td>
<td>33 - 72 mm</td>
</tr>
<tr>
<td>Mh</td>
<td>57 - 126 mm</td>
</tr>
<tr>
<td>Mi</td>
<td>100 - 200 mm</td>
</tr>
</tbody>
</table>

- Light Blue
Evaluation of Mottling
Which pattern size is perceived as mottle?

<table>
<thead>
<tr>
<th>Small Mottles</th>
<th>Large Mottles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Md 6-13mm</td>
<td>Me 11-24mm</td>
</tr>
<tr>
<td>Me 11-24mm</td>
<td>Mf 19-42mm</td>
</tr>
<tr>
<td>Mf 19-42mm</td>
<td>Mg 33-72mm</td>
</tr>
<tr>
<td>Mg 33-72mm</td>
<td>Mh 57-126mm</td>
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</table>
Evaluation of Mottling Texture & Mottling

Small Mottles

Large Mottles

Small Mottles = (Md + 0.5Me) / 1.5
Evaluation of Mottling
Texture & Mottling

Mottling is dominated by the max value of the large mottles

\[ LM = \frac{0.5M_f + \text{max}(M_g, M_h)}{1.5} \]

\[ SM = \frac{M_d + 0.5M_e}{1.5} \]

<table>
<thead>
<tr>
<th>Large Mottle</th>
<th>Sample A</th>
<th>Sample B</th>
</tr>
</thead>
<tbody>
<tr>
<td>avg.</td>
<td>3.8</td>
<td>3.7</td>
</tr>
<tr>
<td>max.</td>
<td>4.6</td>
<td>3.8</td>
</tr>
</tbody>
</table>
Texture & Mottling
Small mottles overlay large mottles and reduce their visibility
Texture & Mottling
Small mottles overlay large mottles and reduce their visibility
Evaluation of Mottling
Texture & Mottling - 2 dimensional graph

Visual Ranking:
- clearly noticeable
- visible
- hardly to recognize
Evaluation of Mottling
Texture & Mottling - 2 dimensional graph

Visual Ranking:
- **clearly noticeable**
- **visible**
- **hardly to recognize**
Evaluation of Mottling
Small & Large Mottles weighted for visual correction

- Small mottles in the range of mm to cm overlay Large Mottling and reduce their visibility.

⇒ Large Mottling needs to be corrected by influence of SM:

\[ M = LM \times (1 - f \times T) \]

\[
\begin{align*}
  f (15°) &= 0.05 \\
  f (45°) &= 0.04 \\
  f (60°) &= 0.03 
\end{align*}
\]

⇒ Texture: Small Mottling with shifted zero (pivotal point):

\[ Texture = SM - 6 \]
Evaluation of Mottling
Texture & Mottling

Visual ranking:

- ✓ clearly noticeable
- ▲ visible
- ◇ hardly to recognize
Mottle-Chart
Example: Medium class models

![Mottle-Chart with data points indicating body panels]
Texture - dependend on color / pigment type

- **White Pearl**
  - 15°: Texture chart showing various mottling levels.
  - 60°: Texture chart showing various mottling levels.

- **Silver**
  - 15°: Texture chart showing various mottling levels.
  - 60°: Texture chart showing various mottling levels.

- **Black Pearl**
  - 15°: Texture chart showing no mottling visible under 60° angle.
  - 60°: Texture chart showing no mottling visible under 60° angle.

Graphs display the texture and mottling at 15° and 60° angles for each color type, illustrating differences in appearance.
Mottling versus Orange Peel
Observing direction

Mottling

Orange Peel

off-specular

in specular direction

specular reflection
# Mottling versus Orange Peel

## Pattern size

<table>
<thead>
<tr>
<th>Mottling</th>
<th>Orange Peel</th>
</tr>
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<tbody>
<tr>
<td>large irregular patches</td>
<td>small, wavy pattern</td>
</tr>
<tr>
<td>25 ~ 200 mm</td>
<td>0.1 ~ 30 mm</td>
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</table>

![Mottling Image](image1)

![Orange Peel Image](image2)

10 x 10 cm
Mottling versus Orange Peel
Pattern size

**Mottling**
- large irregular patches
  - 25 ~ 200 mm
- Sample size: 30 x 50 cm
- Viewing distance: > 3 m

**Orange Peel**
- small, wavy pattern
  - 0.1 ~ 30 mm
- Sample size: 10 x 30 cm
- Viewing distance: < 3 m
Irregular mottle distribution
Measurement hints

- Recommended sample area ~ 30 x 50 cm
- 10 scans in 1 - 2 cm distance
- min. scanlength: 37 cm for Mh
  21 cm for Mg & M
# Mottling versus Orange Peel

## Contrast

<table>
<thead>
<tr>
<th>Mottling</th>
<th>Orange Peel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scattering from pigments</td>
<td>Surface reflection</td>
</tr>
<tr>
<td>very low contrast</td>
<td>high contrast</td>
</tr>
</tbody>
</table>
Visual evaluation

What influences recognition of mottling?

- Reflection of surrounding objects overlays mottling
- Object curvature disturbs visibility
- Blinded by illumination highlights
- Ratio of direct to diffuse illumination
Visual evaluation
On panels – viewing angle and light intensity
Customer relevant evaluation of cloudiness.

Correlation study - panels.
Visual evaluation
On cars

Dimmable light source?

Changing lightning conditions
Reflections
(bags; poster; persons; etc.)

Changing lightning conditions
→ e.g. different angle
Customer relevant evaluation of cloudiness.

Field study – Customer relevance.

– Standardised conditions for the visual evaluation.
Striping
Measurement direction

Paint application
Scan direction
Striping on cars
Horizontal vs. vertical stripes
Striping on cars
Character lines
Striping on cars
Striping and measurement

Light silver
### Striping
Calculation of Mercedes & extended formula

<table>
<thead>
<tr>
<th>Tolerances of Mercedes</th>
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<tbody>
<tr>
<td><strong>Striping 15°:</strong></td>
</tr>
<tr>
<td>• 15° Mh-Mg &lt; 0.5</td>
</tr>
<tr>
<td><strong>Mottling 15°:</strong></td>
</tr>
<tr>
<td>• 15M &lt; 4.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Extended striping formula (Mi included)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Striping 15° / 45° / 60°:</strong></td>
</tr>
<tr>
<td>• $striping = \max(mi - mh; mh - mg)$</td>
</tr>
</tbody>
</table>
Striping
Mottle index and striping index analysis

Tolerances of Mercedes

Striping 15°:
- $15° \text{Mh-Mg} < 0.5$

Mottling 15°:
- $15M < 4.5$

- High Mottling
- High Mottling and Striping
- Mottling and Striping: OK
- Obvious Striping
Striping analysis
Mercedes measurement data on hoods

Hoods
Scanning direction:
- In application direction
- Across application direction

M15d 6-13mm  M15e 11-24mm  M15f 19-42mm  M15g 33-72mm  M15h 57-126mm  M15i 100-200mm
Striping analysis
Mercedes measurement data on hoods

- Mottling 15°
- striping 15° Mh-Mg
- good
- beginning striping
- striping
- cloudy
- Tolerance
Thank you for your attention