Color homogeneity (mottling) of effect basecoats

Validation of the visual evaluation in comparison to automated measurement systems

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Color homogeneity of effect basecoats

Agenda

- Visual assessment of mottling
- ProSim
- cloud-runner
- Conclusion / Outlook
Color homogeneity of effect basecoats

Mottling

- Definition of mottling
  - macroscopic bright / dark shading of the basecoat
    (angle-dependent characteristic)
    - local differences regarding the orientation of the effect pigment particles
    - tinted color shades may additionally show shadings of the tone

- Main causes for imperfect alignment of aluminum flakes
  - critical application parameter
  - application pattern too big (overlap <3)
  - wet and dry areas
  - deviations of the layer thickness
  - insufficient hiding power
Visual assessment of coated panels

- darkened room
- special halogen spot lights providing a critical illumination
- panels are rated at different viewing angles

Visual assessment of mottling

Procedure
Visual assessment of mottling
Gage R&R

A gage R&R (Measurement System Analysis, MSA) was carried out to assess the visual evaluation of mottling:

- number of examiners: 9
- number of panel sets: 5
- number of panels per set: 5-6
- geometry of observation: top view / side view
- classification: in marks (1 to 5) / ranking within test series
  1 = free of mottling
  2 = acceptable mottling
  5 = strong mottling
tendency possible (e.g.: 3.5)
- repetitions: 3 (on separate days)

1404 single assessments
Visual assessment of mottling
Results of gage R&R

- Quite poor results for repeatability*) and reproducibility*)
- Improvement via defining a ranking (a quantitative conclusion is no longer possible)
- Standard deviation is in the range of one mark

*) repeatability: dependent on examiner
   reproducibility: independent from examiner
Visual assessment of mottling
Gage R&R – Conclusion

- Disadvantage of visual assessment of mottling panels
  - very subjective
  - trends within a test series are often hard to identify
  - the human eye is very susceptible to optical illusions
  - tiring for the eyes / lost of concentration
  - repeatability and reliability is questionable

- There is a need for a simple and fast method
  - to objectively
  - measure the magnitude of mottling
  - arrange a ranking within a test series
Visual assessment of mottling

Alternatives

- Target: objective assessment of mottling by using a measuring method that is in accordance with the visual impression.
Color homogeneity of effect basecoats

Agenda

Visual assessment of mottling

ProSim

cloud-runner

Conclusion / Outlook
Evaluating mottling with ProSim
Principle of measuring method

- Scanning measurement of the mottling panels with a spectrophotometer (ProSim-robot)
  - color homogeneity is analyzed locally
  - inhomogeneity is detected as a partial difference of a zone in comparison to the direct surrounding area

local $dE'$: spot compared to its neighbors
Evaluating mottling with ProSim
Principle of measuring method –
Calculation of dE’ according to Audi weighting

\[
\Delta E_{ab}(\gamma) = \sqrt{\left(\frac{\Delta L^*(\gamma)}{g_L \cdot S_L(\gamma)}\right)^2 + \left(\frac{\Delta a^*(\gamma)}{g_a \cdot S_a(\gamma)}\right)^2 + \left(\frac{\Delta b^*(\gamma)}{g_b \cdot S_b(\gamma)}\right)^2}
\]

\[
\Delta E_{CH}(\gamma) = \sqrt{\left(\frac{\Delta L^*(\gamma)}{g_L \cdot S_L(\gamma)}\right)^2 + \left(\frac{\Delta C^*(\gamma)}{g_C \cdot S_C(\gamma)}\right)^2 + \left(\frac{\Delta H^*(\gamma)}{g_H \cdot S_H(\gamma)}\right)^2}
\]

\[
\Delta E_{\text{eff}}(\gamma) = \sigma(\gamma) \cdot \Delta E_{ab}(\gamma) + (1 - \sigma(\gamma)) \cdot \Delta E_{CH}(\gamma)
\]

**local dE’**: spot compared to its neighbors
Evaluating mottling with ProSim
Correlation of mottling images (dE’-graphs) and visual marks
Evaluating mottling with ProSim
Benchmark visual assessment versus ProSim evaluation

- Accuracy of +/- 1 unit (scale from 1-5); not reliable
  - subjective method
  - trends are often hard to identify
  - human eye is prone to illusions
  - tiring for the eye

- Accuracy of +/- 0,3 units (scale from 1-5); very precise
  - objective
  - applicable for statistic analysis
  - independent from “the human factor”
  - disadvantage: speed
Color homogeneity of effect basecoats

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A gage R&R (MSA) was carried out to assess the evaluation of mottling using the cloud-runner

- number of operators: 3 (BYK-Gardener / BASF Coatings)
- number of panel sets: 3 (pure silver / grey metallic / blue metallic)
- number of panels per set: 3
- number of measurements per panel: 10 (10 rows having a distance of 1 cm)
- repetitions: 10
- number of devices: 2 (cloud-runner #899 and #910)
- number of key figures per single measurement: 21 (geometries, sizes, condensed)

113400 single data points
cloud-runner

Gage R&R – Processing the data

- Elimination of outliers that occurred due to surface defects

**Time Series Plot of 15 Texture**

sample = pure silver (144-4)

- 1 = operator 1, #899
- 2 = operator 2, #899
- 6 = operator 3, #910

6 columns (3 operators with 2 cloud-runners), each with 100 data points
Elimination of outliers that occurred due to surface defects

![Time Series Plot of 15 Texture](image)

- such outliers were only found for one panel
- all outliers derive from measuring lane #4

- dirt, dust, fingerprints, etc.

lane #4
Survey of unprocessed data for one specimen (144-2: pure silver)
Survey of unprocessed data for one specimen (144-2: pure silver)

value according to cloud-runner

1 out of 21 key figures

60 dots per lane (3 operators, 10 repetitions, 2 instruments); each dot represents one single measurement

10 lanes per panel

scatterplot
Survey of unprocessed data for one specimen (144-2: pure silver)

No influence of the device
- nearly perfect overlap of red and black dots

However, some significant outliers for #899
- outliers were neglected
Visual assessment of specimens used for MSA

<table>
<thead>
<tr>
<th>Color Shade / Sample Name</th>
<th>144-1</th>
<th>144-2</th>
<th>144-4</th>
<th>150-2</th>
<th>150-3</th>
<th>150-6</th>
<th>154-1</th>
<th>154-3</th>
<th>154-6</th>
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<td></td>
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<tr>
<td>blue metallic</td>
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</tr>
</tbody>
</table>

average mottling mark
cloud-runner
Results of gage R&R – Boxplots for all samples

Boxplot of all key figures for all specimen

panel
cloud-runner
Results of gage R&R – Boxplots for all samples

Boxplot of 15 T

- **Q3**: 75% of all measured values are equal or lower
- **median** (= Q2)
- **outlier**: highest value within upper fence (= Q3 + 1.5 · IQR)
- **Q1**: 25% of all measured values are equal or lower
- **IQR**: lowest value within lower fence (= Q1 - 1.5 · IQR)
Results of gage R&R – Boxplots for all samples

Scatterplot of 15 T vs lane
sample 150-3

Scatterplot of 15 T

calculation of mean value (lane 1 to 10)
boxplot based on 60 means (10 repetitions, 3 operators, 2 devices)
Results of gage R&R – Boxplots for all samples

Boxplot of all key figures for all specimen

search for identical pattern panel
Which cloud-runner-value correlates with the visual impression?
cloud-runner
Results of gage R&R – Correlation with visual impression

- Summary of correlation between visual assessment and cloud-runner
  (based on: boxplots  ➔ 600 single measurements per panel)

- Quality of correlation:
  - green = good
  - yellow = by trend
  - red = no correlation
Calculation of mean (in each case mean of lane 1 to 10)
• Comparison of best and worst panel within pure silver shade series
  - histogram of determined 45 M-values
Comparison of best and worst panel within pure silver shade series

- histogram of determined 45 M-values

Range of values obtained for a single lane is in the same dimension as the difference between 45 M-values for visual mark 1.7 and 5.0.
Comparison of best and worst panel within pure silver shade series

- histogram of determined 45 M-values

significant overlap in the range of approx. 6 to 7 (45 M) for both specimens
Comparison of best and worst panel within pure silver shade series

- **worst case scenario**: only one lane is measured

Example: histogram of 144-1, lane 1 vs. histogram of 144-2, lane 7
Comparison of best and worst panel within pure silver shade series

- **worst case scenario**: only one lane is measured

- Histogram of 144-1, **lane 1-10**
  vs. histogram of 144-2, **lane 1-10**

  **clear differentiation in accordance with visual assessment**

- Example: histogram of 144-1, **lane 1**
  vs. histogram of 144-2, **lane 7**

  **less differentiation; result is contrary to visual assessment**
Comparison of best and worst panel within pure silver shade series

- **best case scenario**: narrow step size (1 cm), calculation of mean (lane 1-10) and many repetitions (10 times per device and per operator)

Standard deviation $\sigma$ of 45 M mean (calculated by averaging 45 M for lane 1 to 10) is very narrow
Example: grey metallic panels measured by 1 operator with 1 device
- grid having width of 1 cm, calculation of means (lane 1-10), 10 repetitions

- the higher the differences between the lanes, the worse the mottling
  (→ high standard deviation)

might be used as weighting factor
For all three color shades investigated within gage R&R-study a correlation with visual assessment was found.

Absolute values for 45 M (as well as for other key figures) are strongly influenced by the color shade.

- No correlation of absolute values with mottling
- Experience with wide range of color shades needed

Same 45 M-value, but significantly different visual mark.
Color homogeneity of effect basecoats

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Visual assessment of mottling

ProSim

cloud-runner

Conclusion / Outlook
Conclusion

Fast and reliable method to assess mottling in accordance with visual impression
- investigated samples exhibited significant differences with respect to mottling
  - reliability for small differences needs to be proven
- no influence of operator and device
- some key figures correlate with the visual evaluation, others don’t
  - relevant key figures need to be defined per color shade
- absolute values depend on color shade

Automated elimination of outliers (e.g. by SMC) preferable
High deviation per lane
- necessity to measure several lanes in parallel
  - well-defined two-dimensional scanning procedure
  - distance between lanes should be 1-2 cm
    - further evaluation necessary

Range of key figures is relatively small compared to range of visual marks
- example: 45 M = 5.3 – 7.6 for silver metallic / corresponding visual mark = 1.5 -5.0
  - ability to differentiate between 0.5 visual marks (relevant for daily work) needs to be proven
  - expanding of cloud-runner values by weighting with standard deviations
- Analysis of cloud-runner raw data according to ProSim-method
  - to visualize mottling (graphical support of evaluation)
  - to take advantage of the high information density in order to calculate mottling in two dimensions
  - to distinguish between different types of mottling (stripes, clusters,....)
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