Visual Inspection of Surfaces

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Experiment Purpose

• Evaluate the parameters that affect visual inspection of cleanliness
  – Current standards do not account for surface type, experience of inspector, etc
  – Result is that surfaces meeting the same standard level may have very different cleanliness
Experiment Design

- Factors tested
  - Surface reflectance
  - Surface roughness
  - Largest particle size
  - Exposure time
  - Inspector

- Measurement
  - Distance to sample
Reflectance Values

- Weighted by cleanroom lamp spectral power distribution
  \[ \rho = \frac{\int_{380}^{780} \rho(\lambda) \cdot s(\lambda) d\lambda}{\int_{380}^{780} s(\lambda) d\lambda} \]

- Three integrated reflectance values used
  - Black Kapton: 0.069
  - Kapton: 0.456
  - VDA: 0.889
Roughness Values

- Rough surface created by pressing sandpaper into film sample
  - Used 60 grit paper
  - 20 psi
  - Approx 270 micron particle size
  - Because of random particle orientation, spacing and depth of indents was irregular
  - Roughness assigned value of 0 for smooth or 1 for rough
Exposure and Particle Size

- Samples exposed to cleanroom fallout for 1-7 days before the visual inspection
- After the visual inspection, the largest particles were collected by tape lift and measured
Test Setup

- Three observers in parallel
- Light behind and to the side of the observers
- Samples arranged in grid on table (random order)
DOE Regression

- Fit up to fourth order interactions
  - Except observer; added interactions one at a time
  - Only first order effects from observer had any statistical significance

- Analysis of Variance
  - Model equation is statistically significant with 99% confidence

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Ratio</th>
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</thead>
<tbody>
<tr>
<td>Model</td>
<td>15</td>
<td>30.762221</td>
<td>2.05081</td>
<td>3.3859</td>
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<tr>
<td>Error</td>
<td>33</td>
<td>19.988016</td>
<td>0.60570</td>
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<tr>
<td>C. Total</td>
<td>48</td>
<td>50.750237</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Prob > F = 0.0017
Model Fit

- Distance predictions are not great
  - Distance at which contamination is seen may depend on more variables than those tested

![Graph showing model fit with R²=0.61, RMSE=0.7783, and p=0.0017.](image)
Parameter Estimates

- Most parameter estimates have confidence of 95% or better
- Three exceptions (highlighted rows)

| Term                                      | Estimate | Std Error | t Ratio | Prob>|t| |
|------------------------------------------|----------|-----------|---------|-----|
| Intercept                                | 8.4987743| 1.043563  | 8.14    | <.0001 |
| Refl                                     | -3.251522| 0.865699  | -3.76   | 0.0007 |
| Rough                                    | -1.285622| 0.648001  | -1.98   | 0.0556 |
| Exposure                                 | -0.405207| 0.166506  | -2.43   | 0.0205 |
| (Refl-0.49455)*(Exposure-4.53849)        | 3.1261103| 0.727024  | 4.30    | 0.0001 |
| (Rough-0.55102)*(Exposure-4.53849)       | 1.6810883| 0.416319  | 4.04    | 0.0003 |
| (Refl-0.49455)*(Rough-0.55102)*(Exposure-4.53849) | -3.622634| 1.110143  | -3.26   | 0.0026 |
| Ferret                                   | 0.0012317| 0.000398  | 3.10    | 0.0040 |
| (Refl-0.49455)*(Ferret-1060)             | -0.004593| 0.001235  | -3.72   | 0.0007 |
| (Rough-0.55102)*(Ferret-1060)            | -0.002424| 0.000905  | -2.68   | 0.0114 |
| (Exposure-4.53849)*(Ferret-1060)         | -0.000301| 0.000254  | -1.19   | 0.2440 |
| (Refl-0.49455)*(Exposure-4.53849)*(Ferret-1060) | 0.002217| 0.000846  | 2.62    | 0.0132 |
| (Rough-0.55102)*(Exposure-4.53849)*(Ferret-1060) | 0.0010646| 0.000442  | 2.41    | 0.0219 |
| (Refl-0.49455)*(Rough-0.55102)*(Exposure-4.53849)*(Ferret-1060) | -0.00146| 0.001253  | -1.16   | 0.2524 |
| Observer[L1]                             | 0.0489993| 0.159809  | 0.31    | 0.7611 |
| Observer[L2]                             | -0.351511| 0.159776  | -2.20   | 0.0349 |
Model Equation

- $8.499 +$
- $-3.252 \times \text{Refl} +$
- $-1.286 \times \text{Rough} +$
- $-0.4052 \times \text{Exposure} +$
- $0.001232 \times \text{Ferret} +$
- $(\text{Refl} - 0.4946) \times (\text{Exposure} - 4.538) \times (3.126) +$
- $(\text{Rough} - 0.5510) \times (\text{Exposure} - 4.538) \times (1.681) +$
- $(\text{Refl} - 0.4946) \times (\text{Rough} - 0.5510) \times (\text{Exposure} - 4.5385) \times (-3.623) +$
- $(\text{Refl} - 0.4946) \times (\text{Ferret} - 1060) \times (-0.004593) +$
- $(\text{Rough} - 0.5510) \times (\text{Ferret} - 1060) \times (-0.002424) +$
- $(\text{Exposure} - 4.538) \times (\text{Ferret} - 1060) \times (-0.0003008) +$
- $(\text{Refl} - 0.4946) \times (\text{Exposure} - 4.538) \times (\text{Ferret} - 1060) \times (0.002217) +$
- $(\text{Rough} - 0.5510) \times (\text{Exposure} - 4.538) \times (\text{Ferret} - 1060) \times (0.001065) +$
- $(\text{Refl} - 0.4946) \times (\text{Rough} - 0.5510) \times (\text{Exposure} - 4.538) \times (\text{Ferret} - 1060) \times (-0.001440) +$
- Match Observer("L1": 0.04900, "L2": -0.3515, "L3": 0.3025)
Response to Variables

- Distance at which surface is visibly contaminated decreases with increasing
  - Reflectance, Roughness, Exposure (PAC)
- Increases with largest particle size
- Is only slightly affected by observer

![Graph showing response to variables]
Discussion

- The light source and observation point was fixed relative to the sample
  - In an actual inspection, the light source is usually hand held, and the observer can move relative to the source
- Perceived roughness may trick the brain into discarding particles
  - Diffuse scatter from increased PAC may have the same effect
- Variability between observers was less than other effects
  - Experience did play a part in differentiating scratches from fibers

Curved VDA Sample

Glare was a significant factor for some samples