Overview

• Measurement of residual stress after annealing
  • Performing the measurement
  • Dependence on the position in the annealing lehr
  • Dependence on the forming process

• Measurement of cord stress
  • Sample preparation
  • Performing the measurement

• Test equipment capabilities (Gage R&R analysis)
  • Repeatability
  • Reproducibility
Measurement of Annealing Stresses

• Monitoring of residual stresses after the annealing process

StrainScope® S3/180 annealing tester
Performing the Measurement

• The highest stresses are to be expected in the contact area to the conveyor belt

• Usually the measurement is therefore done in the base area of the container

• Real temper number (acc. to ASTM C148) or nm/cm is typically used as measuring unit
Dependence on the Position in the Lehr

Left side

Center

Right side
Dependence on the Forming Process

• The residual stress level also correlates with the position in the IS machine

• Possible influencing factors:
  • Mold temperature
  • Mold cooling
  • Distance to annealing lehr

Mean temper number and variance depending on the mold number
Measurement of Cord Stresses

- Cord stress is caused by inhomogeneities in the glass composition
Sample Preparation

• From the cylindrical part of the glass container, a uniformly thick ring (about 1 cm thick) is prepared

• By cutting the ring, circumferential residual stresses are eliminated

• The roughness of the cut surfaces is optically compensated by a suitable immersion liquid (DMP or vegetable oil)
Performing the Measurement

- Since stress cords can be very thin, the measurement must be made with relatively high spatial resolution
- The measuring instrument therefore always only inspects a small section of the sample at a time
- By rotating the Petri dish, the ring is scanned and the maximum tensile stress (shown in red) is identified
- The measurement of the stress value (in MPa or psi) happens automatically and continuously
Assessing the Test Equipment Capabilities using Gage R&R Analysis

• Evaluation of the repeatability (influence of the measuring device) and reproducibility (influence of the operator)

• Recommendation: Three measurement of 5 to 10 samples by 3 operators

• Important: The samples must be representative, i.e. reflect the process spread

• Result: Total variance of the measuring system (Total Gage R&R)

<table>
<thead>
<tr>
<th>R&amp;R</th>
<th>Measuring system suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 10%</td>
<td>Very well suited</td>
</tr>
<tr>
<td>10% &lt; R&amp;R &lt; 20%</td>
<td>Well suited</td>
</tr>
<tr>
<td>20% &lt; R&amp;R &lt; 30%</td>
<td>Conditionally suitable</td>
</tr>
<tr>
<td>30% &lt; R&amp;R</td>
<td>Not suitable</td>
</tr>
</tbody>
</table>
Gage R&R Results (Ordinary Polarimeter)

**Manual Polarimeter**

- **Components of Variation**
  - % Contribution: Gage R&R, Repeat, Reprod, Part-to-Part
  - % Study Var: Gage R&R, Repeat, Reprod, Part-to-Part

- **R Chart by Operator**
  - Parts: a, b, c, d, e, f, g, h
  - UCL = 19.96
  - R = 7.76
  - LCL = 0

- **Xbar Chart by Operator**
  - Parts: a, b, c, d, e, f, g, h
  - UCL = 56.87
  - LCL = 40.76

- **Manual by Parts**
  - Parts: a, b, c, d, e, f, g, h

- **Manual by Operator**
  - Operators: Falco, Matthias, Tom

- **Parts + Operator Interaction**
  - Average:

**Reported by:** DS
**Tolerance:** Total Gage R&R = 60.91%
Gage R&R Results (StrainScope)

**StrainScope S3/180**

- **Gage name:** StrainScope S3/180 (SP-035)
- **Date of study:** 03.12.2013
- **Reported by:** DS
- **Tolerance:**
- **Misc.:** Total Gage R&R = 11.72%

### Components of Variation

- **Percent**
  - **Gage R&R**
  - **Repeat**
  - **Reprod**
  - **Part-to-Part**

### R Chart by Operator

- **Sample Range**
  - **Falko**
  - **Matthias**
  - **Tom**

### Xbar Chart by Operator

- **Sample Mean**
  - **Falko**
  - **Matthias**
  - **Tom**

### StrainScope S3/180 by Parts

- **Parts**
  - a, b, c, d, e, f, g, h

### StrainScope S3/180 by Operator

- **Operators**
  - Falko, Matthias, Tom

### Parts + Operator Interaction

- **Parts**
  - a, b, c, d, e, f, g, h

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Summary

• Automatic, imaging polarimeters simplify the measurement of residual stresses in container glass compared to conventional measuring methods (visual polariscope or polarizing microscope).

• The measurement in real time enables a quick, simple and above all objective assessment of the quality.

• Specially adapted solutions exist for the different measuring tasks (annealing stress, cord stress):
  • StrainScope® S3/180 annealing tester
  • StrainScope® S4/20 cord tester