Key Principles In The Design & Manufacture Of Curved Glass

(With Specific Focus on Visual Quality Acceptance)

Naoki Woodward – 20.03.18
Introduction

1. Visual Quality – flat glass defects
2. Cold bent/hot bent Process
3. Visual Quality – Additional curved glass defects based on process
4. Relevant standards
5. Key comparisons
6. Conclusion
7. Recommendations
Visual Quality
Flat Glass - Visual Quality

Potential issues – heat treated glass

- Roller wave etc
- Anisotropy
- White Haze
- Other issues for alternative flat glass types

Roller wave/bow/edge lift

Anisotropy

White Haze,
Cold Bent Glass

Bending over rigid framework/laminated - Flat panel with corner/s offset (hyperbolic paraboloid), single curved i.e shallow cylindrical/conical

- Process Limitations:
  - Bent over rigid framework
  - Or
  - Site manipulation
  - Or
  - Cold Bent Laminated
Cold Bent – Visual Quality

Potential issues

Bending over rigid framework/Site Manipulation
- Same defects as base flat material
- Over Bending
- Localised edge distortion
- Visually ‘low risk’

Cold bending during lamination
- Same defects as base flat material
- ‘Lensing’ effect
- ‘Spring back’
Hot Bent Glass

Slump Formed (annealed) –
Freeform, Cylindrical, Conical

- Heating of flat float
- Slump into mold
- Cooled
Hot Bent – Visual Quality

Potential issues

**Hot Bent Slumped**
- Coating Defects
- Surface marks/impressions
- Shape Accuracy

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Hot Bent Glass - Radial

Curved tempered or heat strengthened, cylindrical/conical

- Heating of flat float glass
- Rollers drop and glass takes mold form
- Quenching
Hot Bent – Visual Quality

Potential issues

Hot Bent Radial
- Surface distortions – heat treatment
- ‘Flat Zone’
- Coating variation
- Anisotropy
- Surface blemishes – pock/ring marks & cold cracks
- General shape accuracy

Anisotropy
Hot Bent - Freeform

New process - Freeform tempered (double curved)

- Heating of flat float – furnace 1
- Bespoke bar molds – furnace 2
- Rollers drop and glass takes mold form
- Quenching
Hot Bent – Visual Quality

Potential issues

Freeform tempered
- As radial - tempered
- Shape accuracy
- Material inhomogeneity
- Surface blemishes – bar marks
Categorisation of defects affecting visual quality

**OPTICAL QUALITY**
- Distortion due to tempering
- General shape accuracy/twist, etc.
- Material thicknesses

**VISUAL QUALITY**
- Surface Blemishes

**Dimensional Issues**
- Body Faults (inc' laminated defects)
Reference Documents
Visual Acceptance – Specific Curved Glass Standards/Codes

ASTM C1464 (American) Standard Specification For Bent Glass

Dimensional Tolerances
Flat glass standards
Specific ‘surface blemishes’


Dimensional tolerance
Flat glass standards
Specific ‘surface blemishes’
Additional requirements for IGUs
Visual Acceptance – Glass Industry Guidance

GGF (Glass & Glazing Federation - UK) Section 4

GANA (Glass Association Of North America)

BF (Bundesverband Flachglas)-Guide009
Key Comparisons
# Dimensional Accuracy

*Example 1500 x 2500mm high pane, 10mm thick, curved about its long axis*

<table>
<thead>
<tr>
<th></th>
<th>ASTM C1464</th>
<th>BS ISO 11485-2</th>
<th>BF-009</th>
<th>GGF</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Edge Straightness (warp) Deviation</strong></td>
<td>Not Specified</td>
<td>≤ 3mm/m or 2mm whichever is greater = 7.5mm</td>
<td>+/-2mm/m = +/- 5mm</td>
<td>+/-3mm/m = +/- 7.5mm</td>
</tr>
<tr>
<td><strong>Max’ Cross curve/bend deviation (sag)</strong></td>
<td>4.8mm</td>
<td>4mm/m of the length (fig 9) = 10mm</td>
<td>Not specified</td>
<td>+/-3mm/m = +/- 7.5mm</td>
</tr>
<tr>
<td><strong>Max’ Twist Deviation</strong></td>
<td>4.8mm</td>
<td>5mm</td>
<td>+/-3mm/m = +/- 7.5mm</td>
<td>+/-3mm/m = +/- 7.5mm</td>
</tr>
<tr>
<td><strong>Shape Accuracy (nxt)</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Edge Straightness**

**Cross Curve**

**Twist**
Dimensional Accuracy

Shapes Accuracy

BS ISO 11485 Part 2 (European)
>10mm: 1/2T (=5mm)

T=Nominal Thickness of buildup

ASTM C1464 (American)
10mm, 0 to 2.44m girth +/-3.2mm
10mm, 2.44m to > 3.35m girth: +/-4.8mm

Permissible Deviation (mm)
Girth (m)
Visual Acceptance Comparison: Pock Marks

**BS ISO 11485 Part 2 (European)**
2mm max'

Clustering possible

**ASTM C1464 (American)**
1.6mm/2.4mm

Central zone/edge zone

Clustering possible

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NOT TO SCALE!
Visual Acceptance Comparison: Ring Marks

**BS ISO 11485 Part 2 (European)**
Not permitted in general

But 'can' be allowed - discretional

**ASTM C1464 (American)**
1.6mm/2.4mm
305mm min’ spacing

Central zone/edge zone

BS ISO 11485 Part 2
ASTM C1464
## Viewing Criteria

<table>
<thead>
<tr>
<th>Viewing Distance</th>
<th>Conditions</th>
<th>Glass Orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2m</td>
<td>Daylight without direct sunlight, or using a background light suitable for observing blemishes</td>
<td>Vertical</td>
</tr>
<tr>
<td>3m</td>
<td>Daylight without direct sunlight, or using background lighting</td>
<td>Vertical</td>
</tr>
<tr>
<td>3m</td>
<td>Normal daylight conditions, with the angle of observation 90° to the perpendicular part of the glass being assessed. Focus of vision an object not less than 1m behind the surface being assessed</td>
<td>Vertical</td>
</tr>
<tr>
<td>3m</td>
<td>Diffuse daylight, without direct solar radiation or artificial lighting, looking from inside to out and adopting an angle which corresponds to the normal usage of the room/space.</td>
<td>As per installed condition</td>
</tr>
</tbody>
</table>
Conclusion

- Limited guidance – specifically for optical quality
- Not process specific – latest tech
- Freeform geometry
- Coating discoloration
- Flat glass comparisons
- Aspirations
Recommendations

- ASTM/ISO Curved Glass Codes
- Project Assessment
- Process selection
- Chemical Tempering
- Contract samples/VMU
- Project Orientation
- Wholistic Approach
Thanks!

Any questions?
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