Meeting of GRSG - Experts on Plastic Glazing

2010-02-09   BMVBS Bonn, Germany

Polycarbonates
Plastic Glazing – experience and performance tests

- Experience with polycarbonate as glazing material
  - Used as windscreen (example)
  - Further action plan agreed between KRD & BMS includes investigation of used polycarbonate windscreens (optical appearance after life time)
  - Used in locations other than windscreens

- Main safety related difference between glass and polycarbonate
  - Impact resistance comparison

- Abrasion resistance
  - Wear resistance according to Taber compared with car wash test
  - Correlation of car wash to Amtec-Kistler (ISO 20566)
  - Test set-up to investigate wiper resistance
  - Comparison of different glazing materials with regard to wiper resistance

- Further properties of polycarbonate
  - Characteristic polycarbonate bulk properties
  - Weather resistance of coated polycarbonate
Forestry machinery drivers´ caps from John Deere

- **Substrate:** 12 mm thick polycarbonate sheet Makrolon® GP 099 from Bayer Sheet Europe
- **Reason:** extremely demanding requirements for driver safety
  - FOPS (falling-object protective structures) test according ISO 8083
  - OPS (operator protective structures) test according ISO 8084 can ONLY be fulfilled with polycarbonate
- **TIER:** KRD Sicherheitstechnik GmbH
- **Coating:** SHP401 / AS4000 from Momentive Performance Materials GmbH

Drivers´ cap of John Deers new E-Series of vehicles for felling timber using polycarbonate glazing solutions from Bayer MaterialScience AG
SMART For Two side window

- **Substrate:** Makrolon 2607 / Makrolon 2405
- **TIER:** Reiter & Scheffenacker
- **Coating:** PHC 587 (Eurogard)
- **Location:** Rom and Neapel, Italy
- **Life time info:** from 73 to 87 month (1998/1999 to 2005)
- **No. of evaluated parts:** 12 glazing parts from 6 vehicles

Haze values of the transparent part of the windows

![Haze values graph]

Polycarbonates
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Haze values of the transparent part of the windows

All parts show after 6 years on the road a haze value of <1% (not visible to the naked eye)
Ford Cougar head lamp lenses (driver side)

- Wet Coat: SHP 401/ AS4000
- Location: NRW, Germany
- Life time info: 82 month (01.2000 to 11.2006) & 84,000 km

- No. of evaluated parts: 1 part from 1 vehicles

Haze values of the transparent part of the windows

front: haze 2.4 % (stone chipping)
side: haze 1.3 %
Data Content

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Safety is the motivation

“All glazing materials, ..., shall be ... event of shattering ... of injury is reduced ... of bodily injury is reduced as far as possible. The glazing material shall be sufficiently resistant to the incidents likely to occur in normal traffic, ... .”

(ECE R43 from 2000 in chapter 6. General Requirements)

Polycarbonates

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Safety is the motivation

Impact test with a coated polycarbonate (Makrolon AG 2677) side window:

A dart with 6.6 kg weight is falling down from 3 m height on the part at -30°C and there is NO shattering.
ECE R43 mechanical requirements

MECHANICAL STRENGTH TEST
227 g BALL TEST
according to ECE R43 Annex 14, Item 5

A hardened-steel ball with a mass of 227 ± 2 g and a diameter of approximately 38 mm is dropping freely from a height (2 to 5 m) depending on the sheet thickness (≤3 bis ≥6 mm) onto the test pieces having room temperature or -18°C ± 2°C.

...The ball test shall be considered to have given a satisfactory result if the following conditions are met: the ball does not penetrate the test piece, the test piece does not break into separate pieces.

✔ Makrolon AG2677 coated on both sides with polysiloxane lacquers

HEADFORM TEST
according to ECE R43, Annex 14, Item 4

For panes like side windows, back windows and sunroofs which have reduced impact possibilities (classification VIII/B) the drop height shall be 1.5 m. The HIC value is also to be measured.

...The test piece or sample is not penetrated nor shall it break into fully separate large pieces. The HIC value is less than 1000.

✔ Makrolon AG2677 coated on both sides with polysiloxane lacquers
Testing mechanical properties

Impact Toughness using a dart impact test according to DIN 6603

- mass of falling dart: 13kg
- diameter of falling dart: 20mm
- impact velocity from 2m/s to 13m/s
- adjustable temperature

- Basic mechanical properties determined on standard specimen test series
- Transfer on real part behavior by simulation models and spot tests
Dart impact test - results

Fracture pattern at room temperature and an impact velocity of 2,3 m/s

laminated glass  polymethylmetacrylate  polycarbonate

Fracture pattern at -30°C and an impact velocity of 2,3 m/s
Dart impact test - results

The impact of the so called **head form test** correlates (FEM - simulation based on an existing sunroof) with an impact achieved at a drop height of **15cm** using a small drop impact tester with a mass of falling dart of 1.9kg.

- **breakage at 5cm drop height**
- **slivered glass at 20cm drop height**
- **penetration of the film at 100cm drop height**

- **coated & weathered polycarbonate part**
- **no fracture at 120cm drop height**

Laminated automotive glass
Plastic Glazing – experience and performance tests

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ECE R43 abrasion requirements

Wear protection depending on window location is defined via
- max. haze increase after
- certain exposure times
- using defined test set up (Taber Abrasion)

Questions:
- acceptable haze - level?
- real wear during use?

Windscreen: not allowed, resp. not defined
Diver visibility:
- requisite: $\Delta_{haze} (\text{Taber}) < 2\%$ after 1000 cycles
- not requisite: $\Delta_{haze} (\text{Taber}) < 10\%$ after 500 cycles
TEST  Taber® Abraser Test

- **Test scope:**
  resistance against a material having abrasive particles in a resilient binder

- **Test advantage / disadvantage**
  - well known & accepted
  - correlation to real use?

1. rotating specimen holder
2. abrasive wheel CS 10F
3. abraded track on the test plaque
4. 500g load

(ASM D 1044 / DIN 52347)
Taber test - new CS-10F wheels

Info from Taber Industries ([www.cs-10f.com](http://www.cs-10f.com))

Taber’s CS-10F Calibrase® abrading wheels manufactured between October 2002 and September 2004 may produce test results that are different than your historic values.

<table>
<thead>
<tr>
<th>CS-10F (Type I)</th>
<th>CS-10F (Type II)</th>
<th>CS-10F (Type III)</th>
<th>CS-10F (Type IV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red color</td>
<td>Pinkish-red color</td>
<td>Pink color</td>
<td>Brown color</td>
</tr>
<tr>
<td>Original wheels</td>
<td>Low haze reading</td>
<td>High haze</td>
<td>New (now the</td>
</tr>
<tr>
<td>Expired 2003</td>
<td>due to residue</td>
<td>readings</td>
<td>only available)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>wheels</td>
</tr>
</tbody>
</table>

Polycarbonates

Global Innovations - SMP • Dr. Frank Buckel • 2010-02-09 • Page # 17
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</tr>
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<td>High haze readings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brown color</td>
<td>New (now the only available) wheels</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Wheel specification

i.) dimension (45 to 50 mm diameter & 12.5 mm thick) and
ii.) hardness (72 ± 5 IRHD)

No further specifications (e.g. amount or kind of particles, binder material, etc.)

**fulfilled for all types** (besides III), but nevertheless the different wheels generated values for AS4000 coated polycarbonate from < 2 to >10 % (25% for III) after 1000 cycles
Taber test - test method changes

**ASTM D 1044** – ASTM Subcommittee D20.10 has a work item WK4442 that was submitted July 2004 which addresses the proposed changes for ASTM D 1044.

**ANSI Z26.1 Test 17** – In September 2004, SAE’s Safety Glazing Committee received a replacement document for the abrasion resistance tests.

To ensure repeatability and reproducibility, it is advised that you verify the test method being used is current and reflects the most up-to-date version. All companies following ASTM D1044 should be using the test method released in 2005 (referenced as ASTM D1044-05).

**“Important” Changes:**

**Wheel Refacing:**

**Cleaning Procedure:**
- Soft bristle, anti-static brush and isopropyl alcohol soaked lint free cloth (old: ASTM: soft camel’s hair brush)

**Apparatus:**
- Vacuum pick-up nozzle with enlarged opening
Taber test – measurement system and equipment capability

Email from Taber Industries 2007-11-16:
Our quality records for wheel lot AT20D1 indicate that they are within our internal tolerances. Lot CB24D1 also meets our internal specifications, but the quality requirements that are in place for this wheel lot are more stringent than the earlier type IV wheel lots (of which AT20D1 is). After we released the Type IV generation CS-10F wheels, Taber continued to evaluate our manufacturing processes to ensure consistency of our wheels.

The most significant improvement to be implemented from this effort was expanding our testing protocol to incorporate additional materials during our final approval process. Please recognize that you are comparing data from a first release product run with the current wheel. While the wheels may have passed our internal tests, we never went back to confirm if the initial lots would pass the more stringent requirements.

Information Taber: all new wheels are comparable; the first type IV wheels released, still had some variations in quality.

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Taber test – measurement system and equipment capability II

- switching to a new refacing stone increases the measured values
- this effect occurs with all coating systems

Comparison of different coating systems

- strong deviation depending on coating system
- in some cases the deviation is as large as the given limit of 2% $\Delta$ haze
- some tests pass the <2% $\Delta$ haze limit
 TEST  Real car wash test

- **Test scope:**
  resistance against car wash conditions

- **Test conditions:**
  - test plaques getting dirty during outdoor use in Lev & cleaned once a week in a car wash
  - X-shaped, spliced, PE bristle-containing brushes
  - no wax / cleaning agent

- **Test advantage / disadvantage**
  - realistic
  - not standardized
Taber vs. car wash

- no correlation
  - realistic abrasive wear test?

Car wash ?? Taber ??

- the car wash performance of siloxane based wet coats on PC is better than systems which fulfill the “Δ haze (Taber) < 2% after 1000 cycles” - requirement
Car wash - long term results

- **long term performance**
  - Siloxane based wet coat on PC
    - no visible haze even after long term exposure

  ECE R43:
  - “… sufficiently resistant … in normal traffic …”

- **acceptable haze – level?**
  - invisible

* > 50 washing operations: delamination of the plasma layer from the wet coat occurs
TEST Amtec-Kistler (ISO 20566)

- **Test scope:**
  scratch resistance of coatings against laboratory car wash (used to classify car body paints)

- **Test conditions:**
  - gloss or haze determination after 10 washing operations (double strokes) with a
  - penetration depth of the bristle of 100mm using
  - quartz powder as artificial dirt

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Car wash vs. Amtec-Kistler

- good correlation between real and laboratory car wash
- in contrast to the comparison with Taber here the same two systems appear equally suitable

Amtec-Kistler would be a suitable test for glazing parts to check wear resistance against car wash conditions

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Wiper resistance - real vs. lab

- realistic wear test ✓
- invisible haze ✓
  increase (below the hurdle of an (undefined) acceptable one)
Wiper resistance - real vs. lab

**Car wash test**
- good correlation to a standardized laboratory test (ISO 20566)
- Amtec-Kistler test

**Wiper test**
- lab test wiper resistance
- down-size
- check correlation

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TEST Wiper lab test

- **Test scope:**
  - resistance against rubber based wiper

- **Test conditions:**
  - no. of wipe double strokes
  - dry / wet strokes with or without standardized dirt (ISO 12103)
  - different rubber types for the wiper and different substrates

1. fixed test plaque
2. basin for testing under wet conditions
3. wiping direction (back and forth is one double stroke)
4. moving rubber wiper
Wiper lab test results

- resistance depending on test conditions
  - without dirt
  - with water
  - dirt & without water

- systems reaching the “Δ haze (Taber) < 2% after 1000 cycles” criteria are not performing better
Wiper lab test results

Test conditions:
- wipe speed 14cm/s
- load 20g/cm wiper blade
- wiper blade CR type (polychloroprene)
- artificial dirt: mixture of salt and oxides in water according to ISO 6255 & ISO 12103 (Arizona test dust)
- test cycle: 2500 double strokes under wet condition, then removal of the water and 500 double strokes during drying up of the dirt
- test cycles is repeated 11 times
- cleaning of the samples via rinsing with water
- measuring haze

Especially the combination of all “situations” (dirt, wet and dry) during usage of a wiper system seems suitable as test conditions.
## Comparison of different glazing materials

<table>
<thead>
<tr>
<th></th>
<th>Taber Abrasion Test</th>
<th>Amtec-Kistler Test</th>
<th>Laboratory wiper test</th>
<th>Laboratory wiper test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CS 10F wheels (Gen IV); 1000 Cycles</td>
<td>10 double strokes; 1.5 g sand per 1 l water;</td>
<td>3000 double strokes (2500 wet &amp; 500 dry) with dirt</td>
<td>33.000 double strokes wet &amp; dry combination with dirt</td>
</tr>
<tr>
<td>Laminated automotive glass</td>
<td>1,2</td>
<td>0,3</td>
<td>0,1</td>
<td>0,3</td>
</tr>
<tr>
<td>Siloxane based wet coats on PC</td>
<td>2,6 (2 - 7)*</td>
<td>0,8 (0,5 - 1,1)*</td>
<td>0,2</td>
<td>0,6 (0,5 - 1,3)*</td>
</tr>
<tr>
<td>UV curable head lamp lense coatings on PC</td>
<td>7,1 (5 - 7)*</td>
<td>3,1 (2,2 - 4,3)*</td>
<td>0,5</td>
<td>21</td>
</tr>
<tr>
<td>Uncoated plastics</td>
<td>30-40</td>
<td>10-12</td>
<td>9-13</td>
<td>--</td>
</tr>
</tbody>
</table>

* typical values usually obtained with this kind of coating
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Characteristic polycarbonate bulk properties

Bisphenol A – Polycarbonate provides an unique combination of

**Transparency**
Clear transparent, like glass
89% @ 2 mm thickness

**Heat Resistance**
Application range from –40°C up to +120°C

**Toughness**
Notched impact strength (acc. ISO 180-A)
60 ... 90 kJ / m² @ 3.2 mm 23°C

*advantage vs. Glas:*
✓ weight
✓ toughness
✓ design freedom

*advantage vs. PMMA:*
✓ toughness
✓ heat resistance

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Advantages of Polycarbonate Glazing

Weight savings up to 50% vs. glass
- Lower center of gravity
- Reduction of CO₂-emission

Safety & security
- Passenger retention
- Anti “smash-n-grab”

Styling and design
- Design freedom
- Functional integration
Weight savings potential:
- Density of polycarbonate 1.2 g/cm³
- Density of glass 2.5 g/cm³
→ Theoretical weight savings: ~ 50 %
→ Achievable in real applications: 30 – 50 %

Realised weight savings in recent application:
Smart fortwo fixed panoramic roof
- 1.2 m²
→ Weight savings: ~ 40 % (~ 5.5 kg)
Resource Efficiency

Life cycle analysis on automotive glazing

Polycarbonate vs conventional glass

- 1 kg PC saves ~ 14 – 22 kg CO₂-emission along total life cycle, compared to glass.

Source: GUA GmbH, Corporation for Comprehensive Analyses, study commissioned by Bayer MaterialScience
# Makrolon AG2677

**Grades for / Automotive glazing**
- Global grade; MVR (290 °C/1.2 kg) 12.5 cm³/10 min; Medium viscosity; UV stabilized; Easy release;
- Injection molding - Melt temperature 260 - 320 °C; Available in transparent colors only; Automotive glazing; Roof modules

**ISO Shortname**
- ISO 7391-1:PC,M,UL, UL-19-3

## Property

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Condition</th>
<th>Unit</th>
<th>Standard</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rheological properties</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melting volume-flow rate</td>
<td>300 °C, 1.2 kg</td>
<td>cm³/10 min</td>
<td>ISO 1133</td>
<td>12.5</td>
</tr>
<tr>
<td>Molding shrinkage, parallel</td>
<td>60x60x2, 500 bar</td>
<td>%</td>
<td>ISO 294-4</td>
<td>0.65</td>
</tr>
<tr>
<td>Molding shrinkage, normal</td>
<td>60x60x2, 500 bar</td>
<td>%</td>
<td>ISO 294-4</td>
<td>0.7</td>
</tr>
<tr>
<td>Molding shrinkage, parallel and normal</td>
<td></td>
<td>%</td>
<td>ISO 294-4</td>
<td>0.6 - 0.8</td>
</tr>
<tr>
<td>Melting mass-flow rate</td>
<td>300 °C, 1.2 kg</td>
<td>g/10 min</td>
<td>ISO 1133</td>
<td>13</td>
</tr>
<tr>
<td>Mechanical properties (23 °C/50 % r. h.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tensile modulus</td>
<td>1 mm/min</td>
<td>MPa</td>
<td>ISO 527-1-2</td>
<td>2400</td>
</tr>
<tr>
<td>Yield stress</td>
<td>50 mm/min</td>
<td>MPa</td>
<td>ISO 527-1-2</td>
<td>67</td>
</tr>
<tr>
<td>Yield strain</td>
<td>50 mm/min</td>
<td>%</td>
<td>ISO 527-1-2</td>
<td>5.1</td>
</tr>
<tr>
<td>Nominal strain at break</td>
<td>50 mm/min</td>
<td>%</td>
<td>ISO 527-1-2</td>
<td>&gt; 50</td>
</tr>
<tr>
<td>Stress at break</td>
<td>50 mm/min</td>
<td>MPa</td>
<td>ISO 527-1-2</td>
<td>79</td>
</tr>
<tr>
<td>Elongation at break</td>
<td>50 mm/min</td>
<td>%</td>
<td>ISO 527-1-2</td>
<td>120</td>
</tr>
<tr>
<td>Tensile creep modulus</td>
<td>1 h</td>
<td>MPa</td>
<td>ISO 527-1-2</td>
<td>2000</td>
</tr>
<tr>
<td>Tensile creep modulus</td>
<td>1000 h</td>
<td>MPa</td>
<td>ISO 527-1-2</td>
<td>1900</td>
</tr>
<tr>
<td>Flexural modulus</td>
<td>2 mm/min</td>
<td>MPa</td>
<td>ISO 178</td>
<td>2400</td>
</tr>
</tbody>
</table>
ECE R43 weathering requirements

- **TEST RESISTANCE TO THE ENVIRONMENT**

  - Resistance to simulated weathering according to ECE R43 Annex 14 Item 6

  …The total ultraviolet radiant exposure with the long arc xenon lamp shall be 500 MJ/m². During irradiation the test pieces shall be exposed to water spray in continuous cycles. During a cycle of 120 minutes the test pieces are exposed to light without water spray for 102 minutes, and to light with water spray for 18 minutes.

  …The resistance to the simulated weathering shall be considered to have given a satisfactory result if: The light transmittance measured in accordance with annex 3, paragraph 9.1, does not fall below 95% of the pre-weathering value. Additionally, for windows which are required for driver visibility the value shall not fall below 70%. No bubbles or other visible decompositions, discolorations, milkiness or crazing shall occur during weathering.

- Makrolon AG2677 coated on both sides with polysiloxane lacquers
Weathering performance of coated polycarbonate

In contrast to the abrasion resistance where the performance of a protective coating class - defined by the binder material (e.g. siloxane based coating, etc.) - for polycarbonate is all about the same, the weathering performance can vary a lot within the same coating class.

The weathering performance of polycarbonate depends to a large extend on the ability of the coating to filter out the harmful UV radiation. So the combination of the filter effect and its persistency is the key to a longterm weather resistance.

In order to test this long term performance it is necessary to use accelerated weathering methods which allow a to predict the outdoor weathering result with high accuracy.

- **Xenon WOM 0.75** according to ASTM G155 – an accelerated weathering method used by BMS for coated polycarbonate samples
- **Correlation** check of the accelerated weathering Xenon WOM 0.75 with **outdoor weathering**
- **Weathering result** of different coating systems on polycarbonate
Coated PC performance - accelerated weathering

**Xenon WOM 0.75** based on **ASTM G155**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irradiation W/m²nm</td>
<td>0.75</td>
</tr>
<tr>
<td>Light (min)</td>
<td>102</td>
</tr>
<tr>
<td>Light/spray (min)</td>
<td>18</td>
</tr>
<tr>
<td>Black panel temp. (°C)</td>
<td>70</td>
</tr>
<tr>
<td>Inner &amp; outer filter</td>
<td>boro / boro</td>
</tr>
<tr>
<td>Temp. in test (°C)</td>
<td>55</td>
</tr>
</tbody>
</table>

- **good correlation** to outdoor weathering (time to failure, failure mode, YI and haze until failure and UV degradation rate)
- **high acceleration factor**
  (8 times compared to Florida outdoor weathering; 1a FL = 1100h Xenon WOM 0.75 based on radiation energy)
- **time efficient comparison** of different coated PC samples under standardized conditions possible
Coated PC performance – predicted outdoor weatherability

Polycarbonates

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Coated PC performance – predicted outdoor weatherability

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**Polycarbonates**

Global Innovations - SMP • Dr. Frank Buckel • 2010-02-09 • Page # 43

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**Table: Coated PC Performance**

<table>
<thead>
<tr>
<th>Yearly mean of irradiance</th>
<th>Total solar radiation (295-2500nm)</th>
<th>UV-dosis (295-385nm)</th>
<th>UV-dosis @ 340nm</th>
<th>Xenon WOM 0,75</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 W/m²</td>
<td>6310 MJ/m²</td>
<td>303 MJ/m²</td>
<td>3 MJ/m²</td>
<td>1100h</td>
</tr>
</tbody>
</table>

**Diagram: South Florida Average Annual Radiant Exposure (295-385 nm)**

- 310 MJ/m²
- 290 MJ/m²
- 180 MJ/m²

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**Confidential**
Why Xenon WOM 0.75?

The used accelerated weathering method is based on ASTM G155 (Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials) and called Xenon WOM 0.75 (formerly G26mod).

### Why using a Xenon arc as light source?

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Xenon WOM 0.75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irradiation W/m²</td>
<td>0.75</td>
</tr>
<tr>
<td>Light (min)</td>
<td>102</td>
</tr>
<tr>
<td>Light (min)</td>
<td>18</td>
</tr>
<tr>
<td>Black panel temp. (°C)</td>
<td>70</td>
</tr>
<tr>
<td>Inner &amp; outer filter</td>
<td>boro / boro</td>
</tr>
<tr>
<td>Temp. in test (°C)</td>
<td>55</td>
</tr>
</tbody>
</table>

### Why using an irradiation of 0.75 W/m²·nm at 340nm?

3 MJ/m² @ 340nm is the radiation energy in 1 year FL & the same amount is reached in 1100h Xenon WOM 0.75 so

3 MJ/m² @ 340nm ≡ 1a FL

≡ 1100h Xenon WOM 0.75
Spectra comparison for different light sources

- Xenon Alfa HE
- Xenon WOM 0.75
- QUVA
- QUVB
- Solar spectrum AM 1.5

“Xenon light with boro/boro filter” spectrum is similar to the sun but more intense

No radiation in solar spectrum below 300 nm
Advantage compared to other accelerated weathering methods

- Radiation below 300 nm in artificial weathering destroys the coated polycarbonate in a way that will not occur in real life since the solar spectrum has no radiation below 300 nm
  - QUVB has too much radiation below 300 nm to be considered a realistic test for coated polycarbonate
- The Xenon Alfa HE test has such a high radiation dose, that nonlinear effects take place; i.e. no correlation to real life could be found
- The QUVA is a test with good relevance to outdoor weathering, but the radiation intensity is too low; i.e. weathering tests take too long
- Xenon light with boro / boro filter as the Xenon WOM 0.75 has a spectrum similar to the solar spectrum but more intense
  - Ideal combination to achieve a high acceleration factor while still having a good correlation to outdoor weathering for coated polycarbonate
## Comparison of different Xenon WOM weathering tests

<table>
<thead>
<tr>
<th>Xenon WOM according to SAE J1960</th>
<th>Xenon WOM 0.75 according to ASTM G155</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.) 40min light b.) 20min light + rain c.) 60min light d.) 60min dark + rain</td>
<td>Weathering cycle a.) 108min light b.) 12min light + rain</td>
</tr>
<tr>
<td>0,55 Irradiation W/m²nm @340nm</td>
<td>0,75</td>
</tr>
<tr>
<td>2250h Equivalent to 1 year outdoor weathering in FL based on radiation energy</td>
<td>1100h</td>
</tr>
<tr>
<td>quartz / boro Inner &amp; outer filter system to adjust bulb spectrum to sunlight</td>
<td>boro / boro</td>
</tr>
<tr>
<td>Correlation to outdoor weathering</td>
<td>proven**</td>
</tr>
</tbody>
</table>

- Higher acceleration factor (shorter testing time until 1st failure)
- Bad fit to spectral power of sun light * (bad outdoor correlation)

* Significant amount of for PC harmful radiation (<300nm) which is not present in sun light

** Via comparison of 1st failure mode & time, YI & haze values, UV absorber degradation rate

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Spectra comparison for different filter systems

- Sunlight according to ASTM G173-2
- Xenon Ci65 boro/boro 0.5W/m² (DIN ISO) - most common combination for weathering tests (daylight filter system)
- Xenon Ci65 quartz/boro 0.5W/m² (SAE J1960) - weathering tests with somewhat more & shorter UV than sunlight
- Xenon Ci65 quartz/quartz 0.5W/m² - testing with considerably more shorter (unrealistic) UV than global solar radiation

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Comparison of Xenon WOM 0.75 and outdoor weathering in Florida

3 MJ/m² @ 340nm ≡ 1a FL ≡ 1100h Xenon WOM 0.75

⇒ time to failure and failure mode well predicted by Xenon WOM 0.75
⇒ correlation of YI and haze is good till the protection layer is damaged
Comparison of UVAD in Xenon WOM 0.75 and “real” glazing part weathering

UV absorber degradation (UVAD) measurement in the upper 4µm of the coating using surface IR spectroscopy

- Good correlation between real glazing parts and accelerated weathering regarding the UV absorber degradation

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Summary Accelerated Weathering Method

A good correlation exists between Xenon WOM 0.75 (former G26mod) and outdoor as well as “real” glazing part weathering

- The comparison of outdoor and accelerated weathering using siloxane based wet coats 1\textsuperscript{st} gen. on Makrolon\textsuperscript{®} shows that
  - time to failure and failure mode is well predicted in only one eighth of the time

- The UVAD measurement of siloxane based wet coat 1\textsuperscript{st} gen. on Makrolon\textsuperscript{®} used as glazing parts compared with sample plaques after accelerated weathering using surface-IR-spectroscopy shows that
  - acceleration does not induce a markedly different UV absorber degradation and therefore allows a reliable prediction
Coating Systems

siloxane based wet coat 1st generation (e.g. head lamp lenses)
- primerless hard coat with one curing step
- two layer system (adhesion primer & hard coat) with either one (“wet on wet”) or two curing steps

siloxane based wet coat 2nd generation
- two layer system (primer with UV protection & hard coat) with two curing steps (“bake on bake”)

siloxane based wet coat & plasma
- three layer system (adhesion primer, hard coat & plasma layer)

New
siloxane based wet coat 3rd generation
- two layer system (primer with improved UV protection & hard coat)

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Comparison of coating systems
(Xenon WOM 0.75 & transparent samples)

Siloxane based wet coats on AG2677 and wet coat & plasma on clear PC
Comparison of weathering data

2\textsuperscript{nd} vs. 3\textsuperscript{rd} generation on clear Makrolon

- \textsuperscript{2nd} generation siloxane based coatings; 7.2 µm
- \textsuperscript{3rd} generation thin; 7.0 µm
- \textsuperscript{3rd} generation; 8.0 µm

Graph showing:
- Accelerated weathering time (h)
- Yellowness Index
- Haze [%]

Confidential information highlighted.

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Summary of the weathering results

- The weathering performance for different locations can be predicted based on an accelerated (artificial) weathering method and depends mainly on the average irradiation in W/m² for this location.

- It is difficult to give a general statements regarding life time (e.g. in hours accelerated weathering time) due to further influencing factors (coating system used, thickness of the coating system and the polycarbonate substrate used (especially the color)).

- The weathering performance of a coating system on black tinted polycarbonate is reduced compared to clear transparent substrates.

- The first visible weathering failure (e.g. μ-crazes) does not mean that it is necessary to replace the glazing similar to a glass based glazing where the first failure is also only a small visible damage probably due to stone-chipping.

- The first weathering failure for a coated polycarbonate glazing part is an optical issue and not a safety issue.
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Thank You For Your Attention

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