Comparative Tests with Laminated Safety Glass Panes and Polycarbonate Panes at the Federal Highway Research Institute (BASt)

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Oliver Zander, Bundesanstalt für Straßenwesen (BASt)

Leverkusen, Germany, 22 November 2011
• Introduction BASSt and BGS

• Test Programme
  – Motivation
  – Overview
  – Test Setups
  – Investigated Factors

• Results
  – Overview Table
  – Drop Tests with Adult Headform
  – Drop Tests with Phantom Headform
  – Vehicle Tests

• Conclusions
Federal Highway Research Institute (BASt)

- Technical and Scientific Research Institute
- Founded in 1951
- Located since 1983 in Bergisch Gladbach-Bensberg near Cologne
- Responsible to the Federal Ministry of Transport, Building and Urban Affairs (BMVBS)
- Approximately 400 Employees
- Place of Training and Education

Responsibilities

- Scientifically Sound Decision Support on Technical Issues and Questions of Traffic Policy for the Ministry
- Drawing up of Regulations and Standards at National and European Level
Federal Highway Research Institute (BAST) Organisation Chart

President
S. Stick

Equal Opportunity Commissioner
M. Albrecht

Scientific Advisory Council
Chairmanship: W. Rauß

Administration
Z. K. Witte

Human Resources, Legal Services, Procurement and Award
Z1. K. Lames

Information and Communication Technology
Z2. M. Behsner

Finance/Management, Cost Accounting
Z3. H. Bant-Guenther

In-House Management Services, Organisation
Z4. F. Bocks

External Research, Knowldege Management
Z5. I. Gallman

Traffic Concepts, Safety Communication
U1. K. Hofmann

Accident Statistics, Accident Analysis
U2. A. Schohrs

Traffic Psychology, Traffic Medicine
U3. G. Evers

Driver Training, Driver Improvement
U4. G. Willemsen-Lenz

Assessment Agency for Bodies Providing Driving License Services
U5. W. Winter

Traffic Engineering
V. M. Retter

Highway Design, Traffic Flow, Traffic Control
V1. K. Lames

Traffic Statistics, Bitriss, S. Knappe

Environmental Protection
V3. D. Hauser

Highway Equipment
V4. U. Ehlers

Traffic Management and Road Maintenance Services
V5. R. Luhmann

Export Centre
V6. R. Weber

Automotive Engineering
F. A. Saacke

Active Vehicle Safety, Emissions, Energy
F1. J. Gall

Passive Vehicle Safety, Biomechanics
F2. F. Loranz

Vehicle, Pavement Interaction, Acoustics
F3. K. P. Glaeser

Co-operative Traffic and Driver Assistance Systems
F4. C. Lotz

Highway Construction Technology
B. S. Zornat

Road Condition Registration and Evaluation, Measuring Systems
B1. E. Fant

Earthworks, Mineral Aggregates
B2. R. Himmern

Innovations, Change of Climate, Concrete Pavements, Low-Noise Surface Treatments
B3. D. Oltje

Pavement Design and Road Safety Issues
B4. A. F. Künkel-Hinrichs

Asphalt Pavements
B5. R. V. Winter

Chemistry, Environmental Protection Issues, Laboratory Services
B6. V. Irsch

Concrete Structures
B1. P. Harst

Steel Structures, Corrosion Protection
B2. A. Harms-Katzer

Tunnel and Foundation Engineering, Tunnelling Operations, Civil Security
B3. F. Remehaller

Maintenance of Engineering Structures
B4. C. Radr

Menun on this Presidium
H. Research Commissioners

Date: November 2011

Gehring / Zander 22 November 2011 Slide No. 4
Terms of Reference – Section F2

- Passive safety of vehicles and vehicle components, protection criteria, compatibility
- Biomechanics, dummy development
- Tests at the crash test facility
- Contribute to the international activities, in particular EEVC, ESV, EU- and ECE-committees
- Euro NCAP - Passive safety

Head of Section: Dipl.-Ing. Bernd Lorenz
Section F2 is active in all international groups working in the field of passive safety regulations

- European Enhanced Vehicle-safety Committee (EEVC)
- Expert Group of the United Nations on Passive Vehicle Safety (UN/ECE/GRSP)
- International Harmonised Research Activities (IHRA)

For the research activities BASt is equipped with modern testing facilities

- Crash test facility
- Vehicle component test facilities (i.e. pedestrian safety, interior head form testing)
- Component test stands
- Dummy and sensor calibration equipment

A substantial proportion of the research activities are financed by European projects and industry contracts
Test Facilities

Crash Test Facility:

- all legally required tests
- all accident reconstructions
- all tests on road equipment
- max. test velocity 120 km/h
- max. vehicle mass 3,5t
Test Facilities

Hydrobrake:

- sledtests
- payload up to 2 t
- max. deceleration 60g
- max. testspeed 64km/h
Projekts: own, for EU, for third party

Euro NCAP

Compatibility in car to car impact

child seats

Calibration of dummies, sensors

Tests pedestrian protection

Approval of road equipment
BGS Böhme & Gehring GmbH

• Cooperation partner of the Federal Highway Research Institute (BASt) for
  – Dummy and Sensor Certifications
  – Pedestrian Protection Testing
• Founded in 1986
• 15 full-time employees, ca. 6 part-time students
• Located in Bergisch Gladbach, Germany
• Operator of BASt’s Dummy Certification Laboratory
  – Crashdummy Certification, Inspection, Maintenance, Instrumentation work, Test preparation, etc.
  – All Dummy Types incl. BioRid, WorldSid, Q-Series...
  – Transducer Calibrations
BGS Böhme & Gehring GmbH

- Operator of BASt’s Vehicle Component Testing Facility
  - Pedestrian Protection
  - Interior Headform Testing (FMH)
  - Other impact and drop tests

- Working on Pedestrian Protection topics for BASt since 1992:
  - Research activities
  - Development of test procedures (EEVC WG 10 and WG 17, Euro NCAP, …)
  - Participation in working groups (e.g. Euro NCAP Pedestrian Protection group)
  - Homologation and NCAP Testing
  - Testing for third parties
• Development and Distribution
  – Test Equipment
  – Special Tools
• Seminars / Workshops
  – Dummy Basics, Handling, Certification, Usage
  – Pedestrian Protection Testing Procedures
• Annual PraxisConference Pedestrian Protection
• Introduction BASt and BGS

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• Conclusions
Motivation

- The Federal Highway Research Institute was tasked by the Federal Ministry of Transport, Building and Urban Development (BMVBS) to perform tests in order to answer the following questions:

- Does the use of plastic windscreens in vehicles lead to a higher injury risk for vulnerable road users, especially for pedestrians?

- Can the current test procedure (Phantom head drop test) on the approval of glazing according to UN regulation Nr. 43 be used for plastic glazing? Which modifications or extensions might be necessary?
Test Programme - Overview

Executed Tests:

- 18 Drop Tests with Adult Headform
- 12 Drop Tests with Phantom Headform
- 15 Vehicle Impact Tests with Laminated Safety Glass Panes (VSG)
- 22 Vehicle Impact Tests with Polycarbonate Panes (PC)
- 12 Vehicle Impact Tests with Laminated Polycarbonate Panes (L-PC)

Total:

- 30 Drop Tests
- 49 Vehicle Impact Tests
18 Drop Tests with Adult Headform

- Mass: 4.5 kg, Drop Height: 3 m
- Investigated Factors:
  - Material (VSG vs. PC)
  - Fixation (adhesive vs. clamping)
  - PC-pane thickness (5 mm vs. 8 mm)
  - Frame dimension (500 x 1000 mm vs. 570 x 1170 mm)
12 Drop Tests with Phantom Headform

- Mass: 10 kg, Drop Height: 3 m
- 8 mm PC panes
- Frame according to UN R43
- Investigated Factors:
  - High Temperature (110°)
  - Low Temperature (-18°)
  - [Material (VSG vs. PC)]
49 Vehicle Impact Tests

- 15 Vehicle Impact Tests with Laminated Glazing Panes (VSG)
- 22 Vehicle Impact Tests with Polycarbonate Panes (PC)
- 12 Vehicle Impact Tests with Laminated Polycarbonate Panes (L-PC)
49 Vehicle Impact Tests

- Investigated Factors:
  - Material (VSG vs. PC)
  - PC pane thickness (5 mm / 6 mm / 8 mm)
  - PC pane construction (monolithic vs. laminated)
    - (L-PC: 3 mm PC/1,2 mm foil/3 mm PC)
  - Test point position
    - 1 = Windscreen base
    - 2 = Glazing without structure within range
    - 3 = Glazing with underlying structure
    - 4 = Next to A-pillar (100 mm distance)
  - Impact Angle (35° vs. 28°)
Vehicle Impact Tests

Impact Angle: 35° vs. 28° to the horizontal

- 35°: Impact angle acc. to R(EC)78/2009; industry raised concerns about VW T5 windscreen angle being representative.
- 28°: The difference of 7° was determined as an average difference between the windscreen angle of the T5 and current sedan vehicles.
Test Programme - General

- Impactor certification before test series according to Regulation (EC) 631/2009 (Adult Headform) and DIN 52310 Part 2 (Phantom Headform), respectively
- Use of damped accelerometers for adult headform
- Photographic documentation
  - Pre test
  - Post test
- High speed video documentation
  - At least two views per test
- Tests with adhesive: Drying time at least 24 hours between application and test
- Calculation of resultant accelerations and HIC values according to Regulation (EC) 631/2009

\[
HIC = \left\{ \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} u(t) dt \right\}^{2/3} \cdot (l_2 - l_1)
\]

- Three tests with each test setup (unless otherwise stated in this presentation)
### Test Programme – Flat Panes

**Mass Comparison**

<table>
<thead>
<tr>
<th>Pane Type</th>
<th>Dimension [mm]</th>
<th>Mass [kg]</th>
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<tbody>
<tr>
<td>VSG 4.5 mm (2,1 outer pane, 1,6 inner pane)</td>
<td>1100 x 500 (1170 x 570)</td>
<td>5.5 (6.7)</td>
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<tr>
<td>PC 5 mm</td>
<td>1170 x 570</td>
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<td>PC 6 mm</td>
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<td>PC 8 mm</td>
<td>1170 x 570</td>
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</table>
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• Conclusions
Tests with phantom head to VSG glazing showed large scatter. Maybe resulting from error in data acquisition system.
### Results - Overview

#### Vehicle Tests (1)

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<td>35°</td>
<td>735.3</td>
<td>875.6</td>
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</table>

1) Tests not performed because of enormous rebound of the impactor. No further test with PC glazing on impact pos. 2 was performed.
### Results - Overview

- **Vehicle Tests (2)**

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<td>3</td>
<td>PC</td>
<td>6 mm</td>
<td>Adhesive</td>
<td>RT</td>
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<td>T5</td>
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<td>RT</td>
<td>35°</td>
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<td>BSVFA-M4-6-1</td>
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<td>RT</td>
<td>35°</td>
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<td>8 mm</td>
<td>Adhesive</td>
<td>RT</td>
<td>35°</td>
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<td>3</td>
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<td>35°</td>
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<td>PC</td>
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<td>35°</td>
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<td>RT</td>
<td>35°</td>
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<tr>
<td>74</td>
<td>BSVFA-MV1-7-1</td>
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<td>T5</td>
<td>3</td>
<td>L-PC</td>
<td>7,2 mm</td>
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<td>RT</td>
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<td>75</td>
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<td>Adhesive</td>
<td>RT</td>
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<td>1,6</td>
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<td>RT</td>
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<tr>
<td>79</td>
<td></td>
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<td>T5</td>
<td>4</td>
<td>L-PC</td>
<td>7,2 mm</td>
<td>Adhesive</td>
<td>RT</td>
<td>35°</td>
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<td></td>
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<tr>
<td>80</td>
<td>BSVFA-MV3-7-1</td>
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<td>4</td>
<td>L-PC</td>
<td>7,2 mm</td>
<td>Adhesive</td>
<td>RT</td>
<td>35°</td>
<td>844,1</td>
<td>848,9</td>
<td>0,7</td>
</tr>
<tr>
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<td></td>
<td>3</td>
<td>Adult Head 4,5 kg</td>
<td>T5</td>
<td>4</td>
<td>L-PC</td>
<td>7,2 mm</td>
<td>Adhesive</td>
<td>RT</td>
<td>35°</td>
<td>847,2</td>
<td>847,2</td>
<td></td>
</tr>
</tbody>
</table>

2) Tests not performed because the first results from tests with 6 mm PC glazing were comparable with 5 mm and/or 8 mm PC material.
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• Conclusions
Sample videos:

- 8 mm PC glazing
- VSG glazing
Drop Tests with Adult Headform

All Tests

HIC Values

|-------------|-------------|-------------|-------------|-------------|-------------|-------------|

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22 November 2011
Drop Tests with Adult Headform

VSG vs. PC

Mean HIC Values

VSG vs. PC Bar Chart

HIC

VSG 5 mm
PC 5 mm
PC 5 mm
PC 8 mm
PC 8 mm
PC 8 mm

339.6
666.5
863.7
1104.6
907.2
806.6

VSG

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Drop Tests with Adult Headform

VSG vs. PC

Coefficient of Variation [%]

VSG 5 mm  PC 5 mm  PC 5 mm  PC 8 mm  PC 8 mm  PC 8 mm

1.9  1.3  2.6  2.3  3.4

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Drop Tests with Adult Headform

Adhesive vs. Clamping

Mean HIC Values

- Base Frame PC 5 mm Adhesive: 666.5
- Base Frame PC 5 mm Clamping: 863.7
- ECE Frame PC 8 mm Adhesive: 806.6
- ECE Frame PC 8 mm Clamping: 907.2

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Drop Tests with Adult Headform

PC Pane Thickness

Mean HIC Values

HIC

5 mm

8 mm

Base Frame PC 5 mm Adhesive

Base Frame PC 8 mm Adhesive

666.5

1104.6

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Drop Tests with Adult Headform

Frame Dimensions

Base

500 x 1000 mm

ECE

570 x 1170 mm
Drop Tests with Adult Headform

Frame Dimensions

Mean HIC Values

- Base Frame PC 8 mm Adhesive
- ECE Frame PC 8 mm Adhesive

HIC

Base

ECE

1104.6

806.6
Summary 1: Drop Tests with Adult Headform

- No visible damage of the PC panes
- HIC Values significantly higher with PC glazing
- Higher scatter with glass panes
- Clamping of PC panes lead to higher HIC results than bonding
- HIC increases with thickness of PC panes
- Frame dimensions according to UN R 43 lead to lower HIC results
- Current Requirement according to UN R 43 (HIC 1000 with Phantom head) was met in tests with ECE frame
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Drop Tests with Phantom Headform

• Sample videos:

8 mm PC glazing  VSG glazing
Drop Tests with Phantom Headform

All Tests with PC panes

HIC Values

- BSVEPM8E-LT1
- BSVEPM8E-LT2
- BSVEPM8E-LT3
- BSVEPM8E-NT1
- BSVEPM8E-NT2
- BSVEPM8E-NT3
- BSVEPM8E-HT1
- BSVEPM8E-HT2
- BSVEPM8E-HT3

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Drop Tests with Phantom Headform

Temperature Effect

Mean HIC Values

-18°: 883.5
RT: 778.9
+110°: 857.6

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Drop Tests with Phantom Headform

Temperature Effect

Coefficient of Variation [%]

-18°: 10.8%
RT: 3.9%
+110°: 7.2%

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Drop Tests – Comparison

Adult Headform (4.5 kg) vs. Phantom Headform (10 kg)

Mean HIC Values

- Adult Headform (4.5 kg)
- Phantom Headform (10 kg)

Adult

Phantom

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Drop Tests with Phantom Headform

- No visible damage of the PC panes
- HIC values seem to increase with lower and higher temperature
- Scatter in high and low temperature test results too high to rely on tendency
- Scatter increases in tests with low and high temperature
- These observations may also result from the rubber properties because the whole test setup was preconditioned (except headform). This represents more realistic situations, not laboratory conditions.
- High temperature (110°) was chosen due to the laboratory capabilities. At lower temperatures (e.g. 40°C) no tests were performed because no significant influence was expected.
- Comparison between drop tests with Adult headform and Phantom headform on 8 mm PC pane show higher results in adult headform test
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Vehicle Impact Tests

All Tests

HIC Values

VSG
PC

HIC

0,0
200,0
400,0
600,0
800,0
1000,0
1200,0
1400,0
1600,0
1800,0

BSVFA-V1-1
BSVFA-V1-2
BSVFA-V1-3
BSVFA-V2-1
BSVFA-V2-2
BSVFA-V2-3
BSVFA-V3-1
BSVFA-V3-2
BSVFA-V4-1
BSVFA-V4-2
BSVFA-V4-3
BSVFA-V4-28-1
BSVFA-V4-28-2
BSVFA-V4-28-3
BSVFA-M1-1
BSVFA-M1-2
BSVFA-M1-3
BSVFA-M1-6-1
BSVFA-M1-8-1
BSVFA-M1-8-2
BSVFA-M1-8-3
BSVFA-M3-1
BSVFA-M3-2
BSVFA-M3-3
BSVFA-M3-6-1
BSVFA-M3-8-1
BSVFA-M3-8-2
BSVFA-M3-8-3
BSVFA-M3-8-4
BSVFA-M3-8-5
BSVFA-M3-8-6
BSVFA-M4-1
BSVFA-M4-2
BSVFA-M4-3
BSVFA-M4-6-1
BSVFA-M4-8-1
BSVFA-M4-8-2
BSVFA-M4-8-3
BSVFA-MV1-7-1
BSVFA-MV1-7-2
BSVFA-MV1-7-3
BSVFA-MV3-7-1
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BSVFA-MV3-7-3
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BSVFA-MV4-7-2
BSVFA-MV4-7-3
BSVFA-MV4-28-1
BSVFA-MV4-28-2
BSVFA-MV4-28-3

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Vehicle Impact Tests

All Tests

- Three tests were performed with each test setup, except
  - Tests with PC glazing on impact location 2, because of the extensive rebound of the headform along with a very low hic value in the first test.
  - Tests with 6 mm PC glazing, because the results were comparable with 5 mm and/or 8 mm PC material. However, the results of the single tests with the 6 mm PC panes are included in the following diagrams

- In the following comparison diagrams, the tests with 28° impact angle are excluded
Vehicle Impact Tests

- Sample videos:

  8 mm PC glazing

  VSG glazing
Vehicle Impact Tests

All Tests

Mean HIC Values

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Vehicle Impact Tests

Comparable Tests

Mean HIC Values: 35°, Pos. 1, 3, 4

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Vehicle Impact Tests

VSG vs. PC

Pos. 1: Mean HIC Values

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Vehicle Impact Tests

VSG vs. PC

Pos. 3: Mean HIC Values

VSG
PC 5 mm
PC 6 mm
PC 8 mm
L-PC 7.2 mm

VSG 5 mm Pos 3 35°
PC 5 mm Pos 3 35°
PC 6 mm Pos 3 35°
PC 8 mm Pos 3 35°
L-PC 7.2 mm Pos 3 35°
Vehicle Impact Tests

VSG vs. PC at Pos. 3

VSG vs. 5 mm PC

VSG vs. 8 mm PC

L-PC
Vehicle Impact Tests

VSG vs. PC at Pos. 3

• VSG Glazing

• L-PC Glazing
Vehicle Impact Tests

VSG vs. PC

Pos. 4: Mean HIC Values

VSG 5 mm Pos 4 35°
PC 5 mm Pos 4 35°
PC 6 mm Pos 4 35°
PC 8 mm Pos 4 35°
L-PC 7.2 mm Pos 4 35°
Vehicle Impact Tests

VSG vs. PC

Coefficient of Variation [%]: 35°, Pos. 1, 3, 4

- VSG
- PC 5 mm
- PC 8 mm
- L-PC 7.2 mm

<table>
<thead>
<tr>
<th>Position</th>
<th>VSG 5 mm</th>
<th>PC 5 mm</th>
<th>PC 8 mm</th>
<th>L-PC 7.2 mm</th>
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<tr>
<td>1</td>
<td>13.6</td>
<td>7.6</td>
<td>7.7</td>
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<tr>
<td>3</td>
<td>13.4</td>
<td>5.0</td>
<td>2.2</td>
<td>1.6</td>
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<tr>
<td>4</td>
<td>11.0</td>
<td>7.6</td>
<td>4.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Graphical representation showing the comparison of Vehicle Impact Tests between VSG and PC, with specific data points for positions 1, 3, and 4.
Vehicle Impact Tests

VSG vs. PC: Pos. 2

HIC Values

- VSG
- PC 5 mm

BSVFA-V2-1
BSVFA-V2-2
BSVFA-V2-3
BSVFA-M2-1

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Vehicle Impact Tests

Impact Angle, Pos 4: 35° vs. 28°

Mean HIC Values

- VSG 5 mm Pos 4 35°: 398.9
- VSG 5 mm Pos 4 28°: 195.8
- L-PC 7.2 mm Pos 4 35°: 883.6
- L-PC 7.2 mm Pos 4 28°: 848.9
Vehicle Impact Tests

Impact Angle, Pos. 4: 35° vs. 28°

Coefficient of Variation [%]

VSG
L-PC

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Vehicle Tests

- No visible damage of the PC panes
- HIC values in tests with PC glazing at three (out of four) impact locations significantly higher than in tests with glass.
- However, at impact pos. 2, the single test performed on 5 mm PC glazing shows significantly lower results than all three tests with VSG.
- At impact pos. 1 (windscreen base) the HIC results of the tests with PC panes decrease with increasing pane thickness.
- At impact pos. 3 and 4 the influence of the different pane thicknesses on the results is not significant.
Vehicle Tests

- The scatter in tests with 8 mm PC and 7.2 mm L-PC glazing is significantly lower than in tests with VSG and 5 mm PC glazing.

- The influence of the impact angle on VSG panes is significant: a lower impact angle results in lower HIC values and lower scatter.

- The influence of the impact angle on PC glazing is marginal with respect to HIC results and scatter.
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• Conclusions
1. Does the use of plastic windscreens in vehicles lead to a higher injury risk for vulnerable road users, especially for pedestrians?

Generally, higher HIC values were observed in tests with PC glazing. As the HIC is the current criterion for head injury severity assessment, PC glazing has to be seen as more injurious in terms of vulnerable road user protection.

In addition, the significantly higher rebound of the head in tests with PC glazing is suspected to lead to higher neck injury risks and may also cause higher injury risks in secondary impacts.

However, as in all tests with PC glazing no damage of the panes were observed, the risk of skin cut injuries might be significantly reduced.
2. Can the current test procedure (Phantom head drop test) on the approval of glazing according to UN regulation Nr. 43 be used for plastic glazing? Which modifications or extensions might be necessary?

As the test procedure prescribed in UN R 43 is generally accepted as a methodology to approve glass windscreen, this test series gives no indication that it is not feasible for PC glazing, especially because UN R 43 does not reflect any pedestrian protection aspects.

The performance of the windscreen area according to the upcoming UN Regulation for pedestrian protection will initially not be relevant for vehicle type approval. However, pedestrian protection should be considered for plastic windscreens to ensure at least the same level of protection as glass windscreens.
We thank the following companies for their kind support to this project:

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- Saint Gobain
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