TECHNISCHE HOCHSCHULE MITTELHESSEN

Institute of Mechanics and Materials

Ansys / DYNARDO | presented at the 17th Weimar Optimization and Stochastic Days 2020 | Source: www.dynardo.de/en/library

Robustness Evaluation of the Pedestrian Head Impact on an automotive Windscreen

Dynardo WOST 2020
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Motivation & Aim

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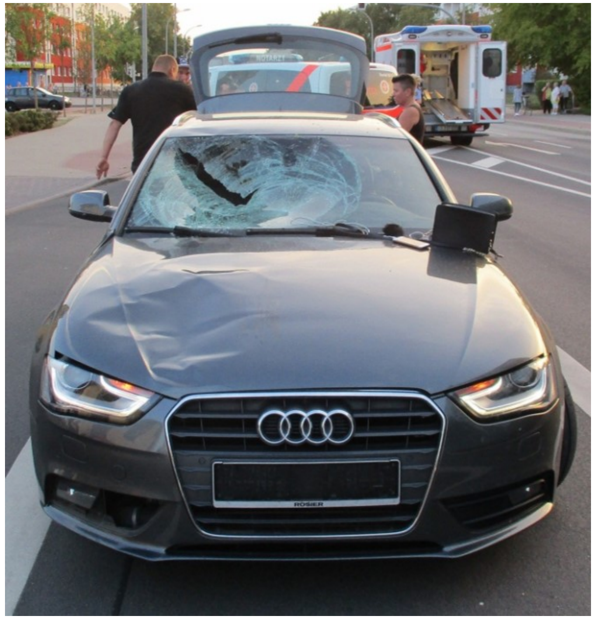
- 1.25 million death due to road crashes 2013 (WHO)
  - ~3,500 deaths per day
  - 22 % Pedestrians: 770 deaths per day (Germany: 1,4 deaths per day)
- Top cause of death among people aged 15–29 years, 2012
- 90% of all road deaths occur in countries that own 50% of all vehicles

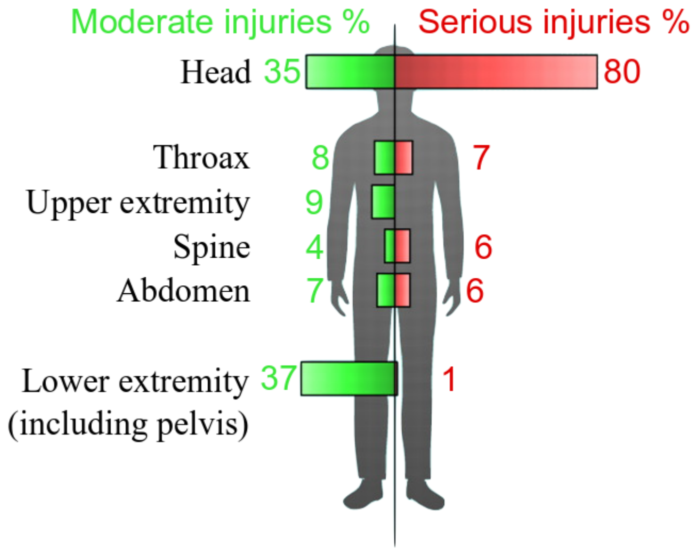


www.bild.de

www.augsburger-allgemeine.de

Motivation & Aim

- Stochastic Fracture Behavior of Automotive Windscreens
  - Pedestrian / occupant head impact
  - Head injury criterion (HIC) distribution
  - Possibility of FE simulations
- State of the Art
  - Non-local failure of glass (Pytel 2011 / Alter 2017)
  - Small number of tests available (NCAP)
  - No consideration of the stochastic fracture behavior
- Aims
  - Model for stochastic failure calculations of glass
  - HIC distribution prediction



Crandall, Jeffrey R., Kavi S. Bhalla, and N. J. Madeley. "Designing road vehicles for pedestrian protection." Bmj 324.7346 (2002): 1145-1148.

Agenda

Pedestrian Head Impact
Head Injury Criterion | FE Model | Initial Simulation

Robustness Evaluation
Influencing Parameters | C-Class Windscreen Analysis

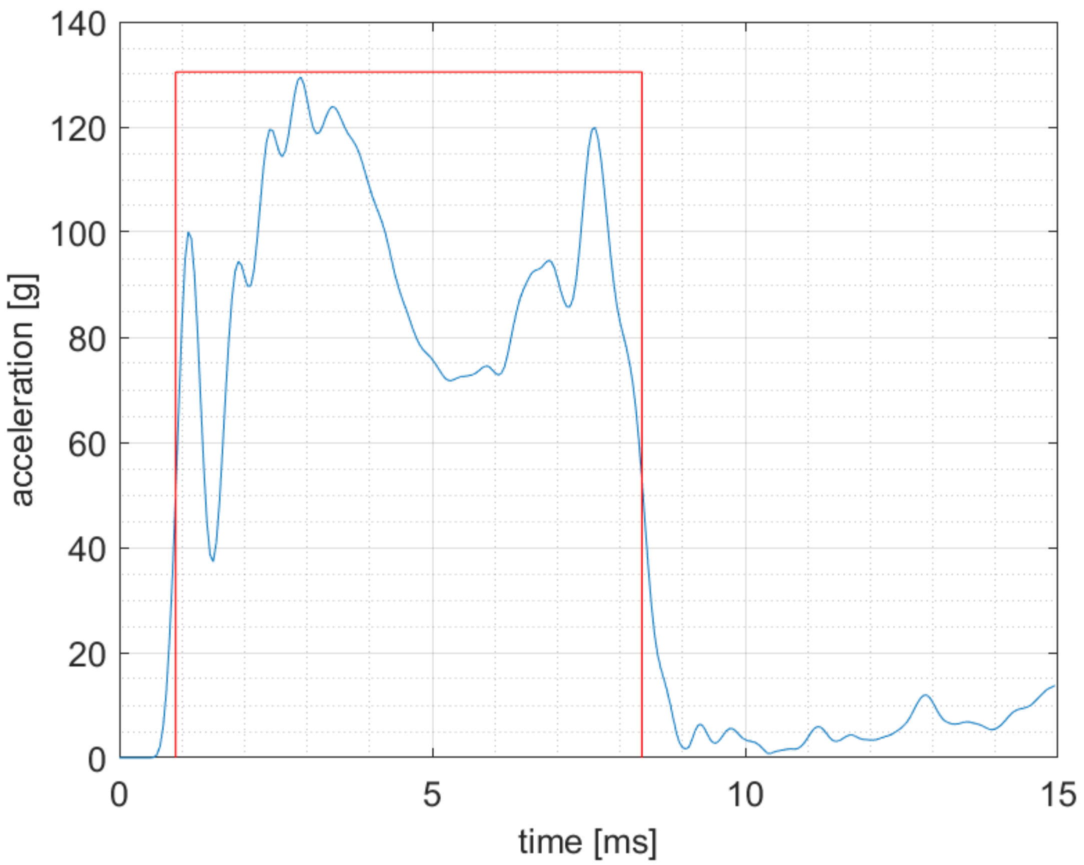
Conclusions
Summary & Outlook | Acknowledgement

Pedestrian Head Impact – Head Injury Criterion

- Resulting acceleration [g] versus time [ms] during impact
- Head Injury Criterion (HIC) to evaluate injury risk

$$HIC = max\left\{\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}(t_2 - t_1)\right\}$$

- Strength of glass and thus the HIC are subject of stochastic scatter



Stochastic Head Injury Criterion – Model

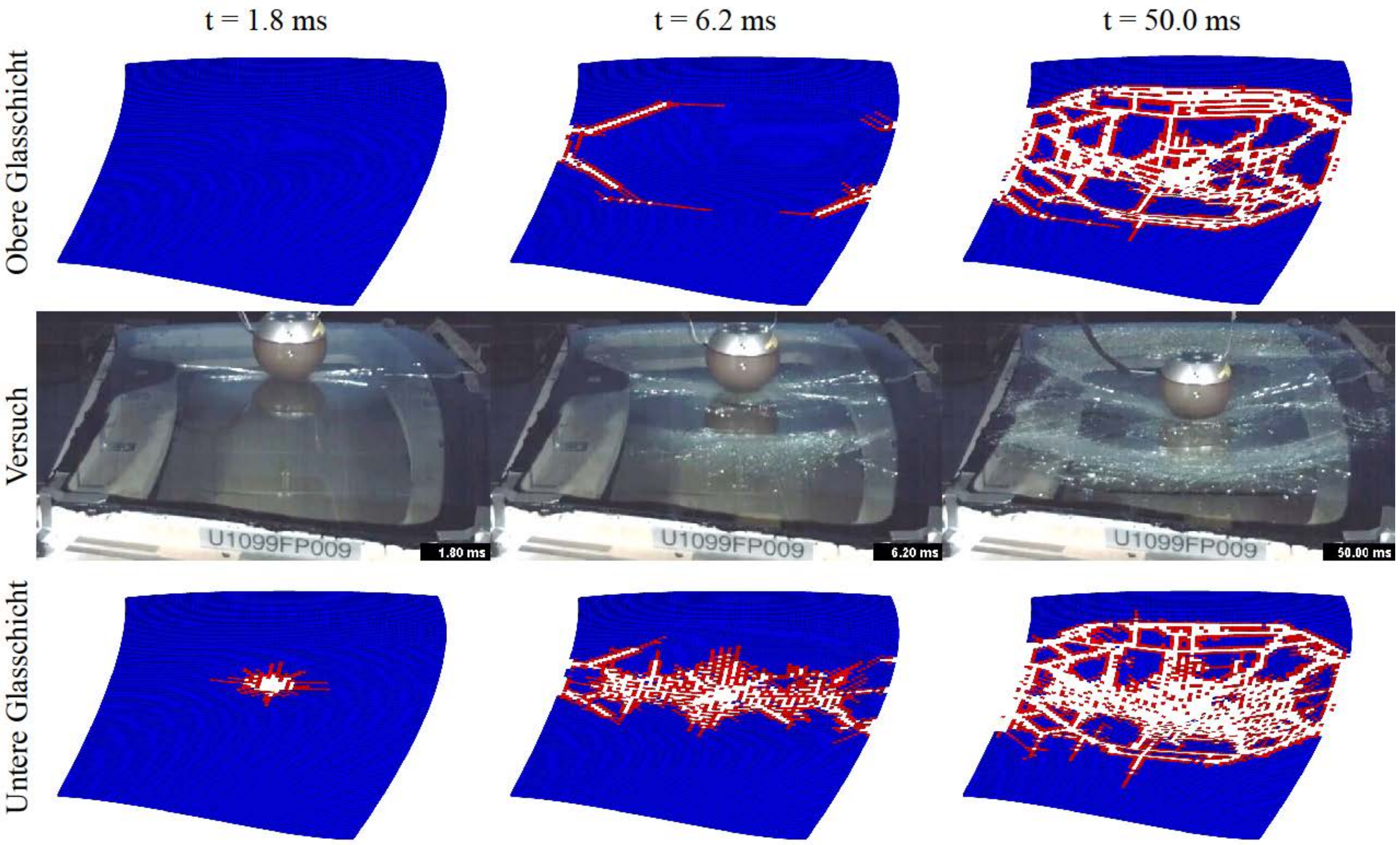
- Used model consists of a Mercedes C-Class windscreen
- Glass failure by /fail/alter (Radioss)
- Windscreen glued to wooden frame
- Impactor according to EuroNCAP

FE Model Mercedes C-Class Windscreen

Robustness Evaluation – Initial Simulation

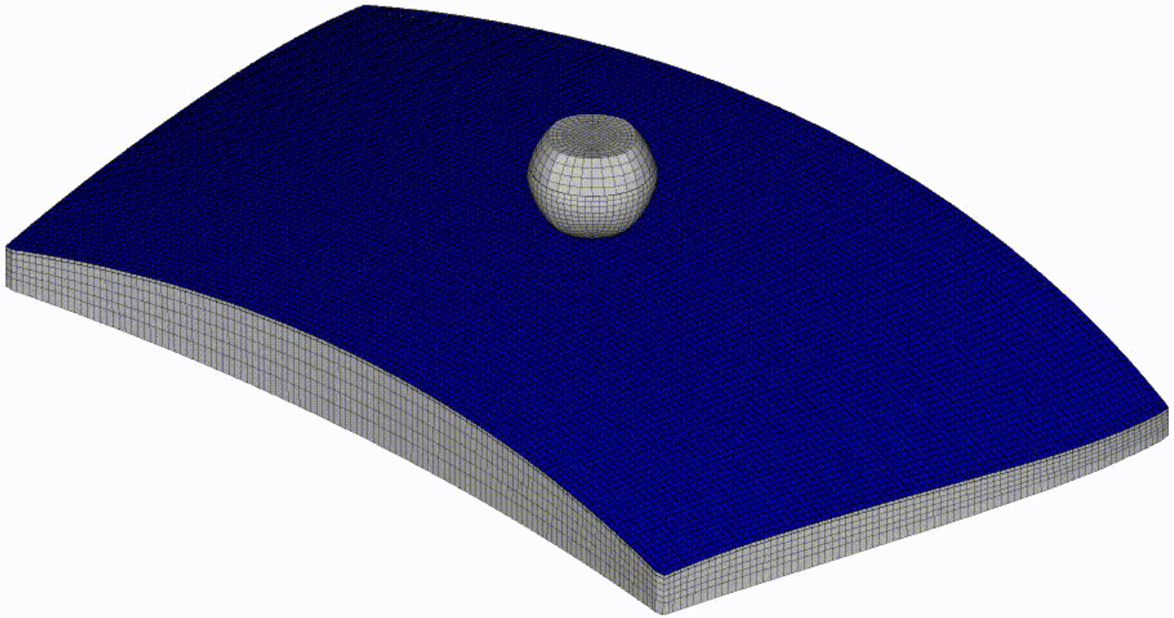
- Failure model validated by head impact test
- For a detailed validation or more information about the failure model see the original paper:

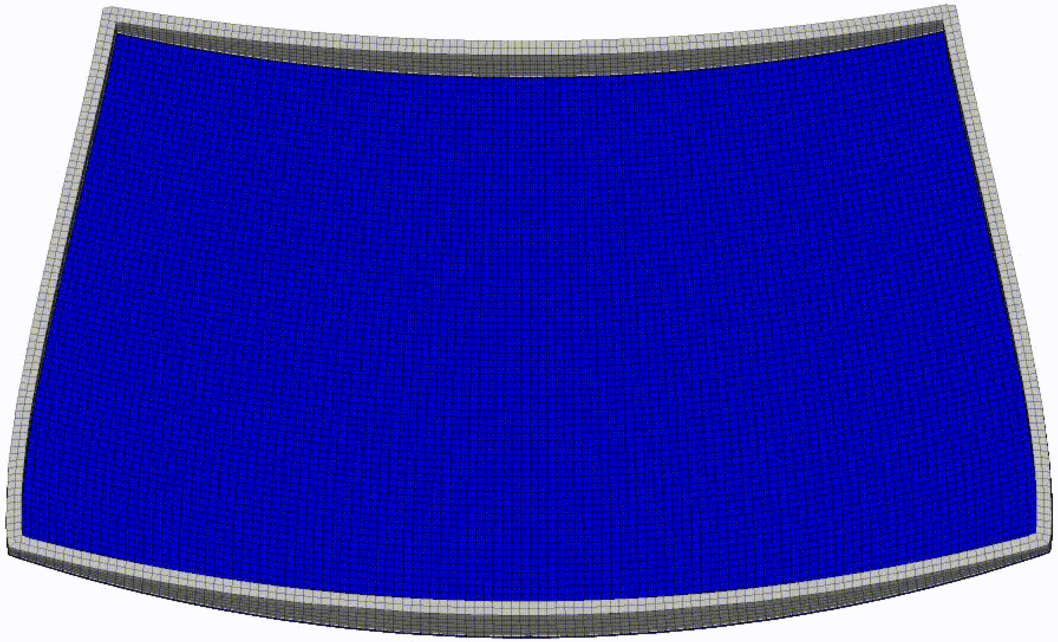
Alter, C., S. Kolling, and J. Schneider. "An enhanced non–local failure criterion for laminated glass under low velocity impact." *International Journal of Impact Engineering* 109 (2017): 342-353.



Stochastic Head Injury Criterion - Initial Simulation

- Three head impact experiments for C-Class windscreen
- Simulation with standard parameters -> HIC = 666.66





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Robustness Evaluation - Influencing Parameters

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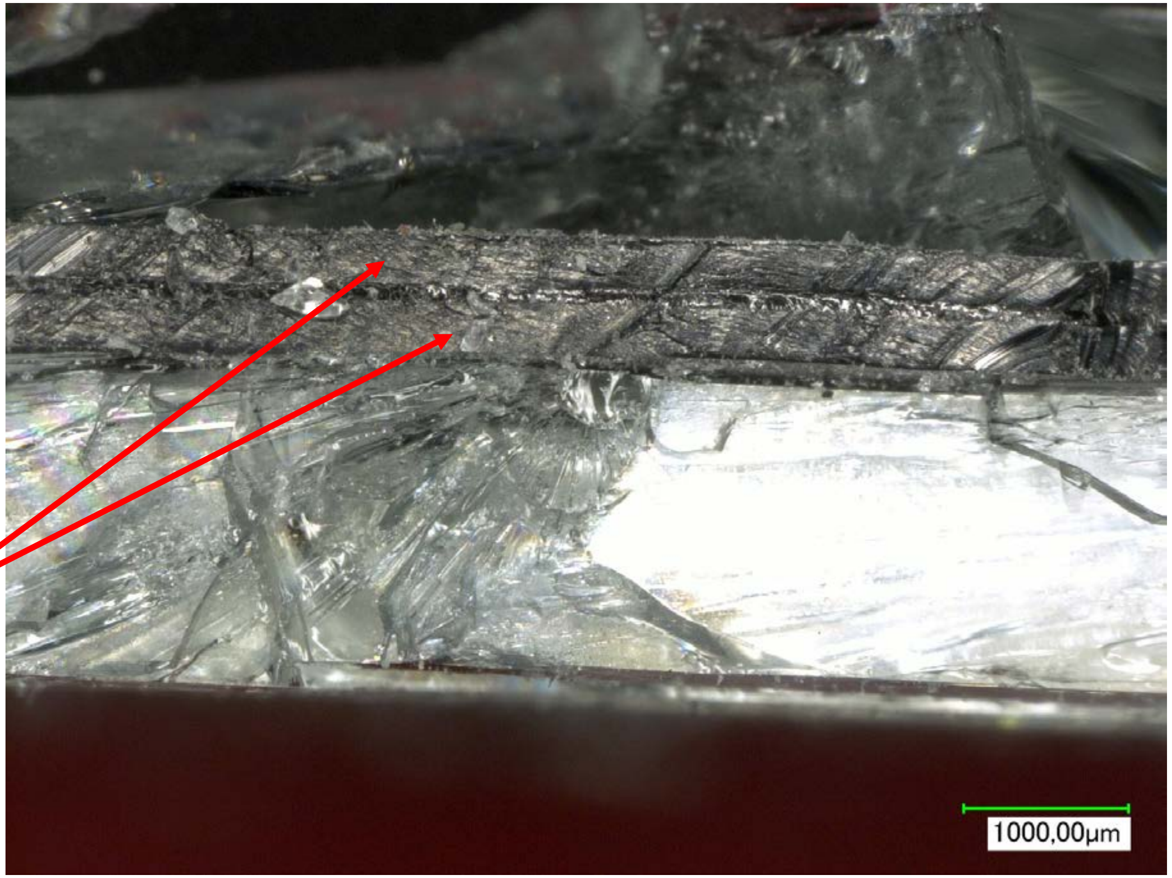
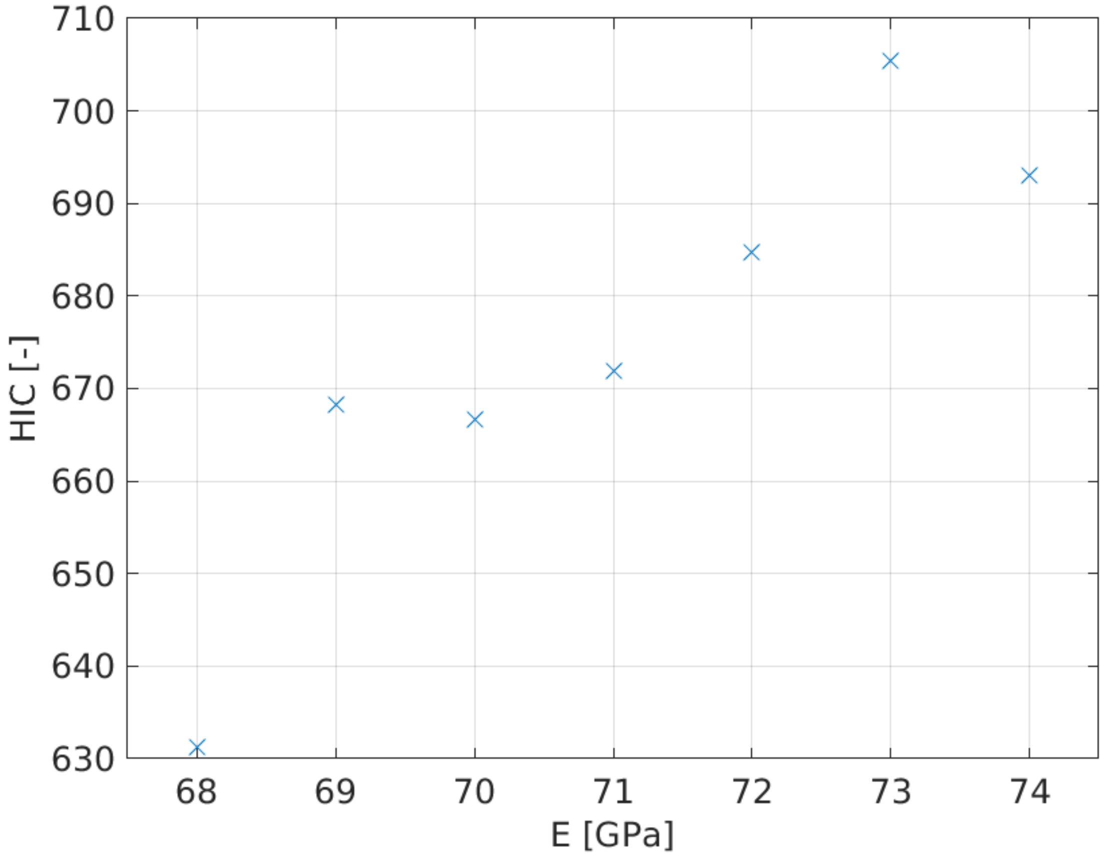
- Mercedes C-Class windscreen consists of two glass panes (each 1.8 mm) bounded by a PVB double interlayer (0.78 mm)
- Parameters with possible influence on HIC:
    - Modulus of elasticity for glass
    - Mechanical behavior PVB
    - Length of initial flaws
    - Glass ply thickness
    - Impact velocity
    - Impact position



Robustness Evaluation – Modulus of Elasticity

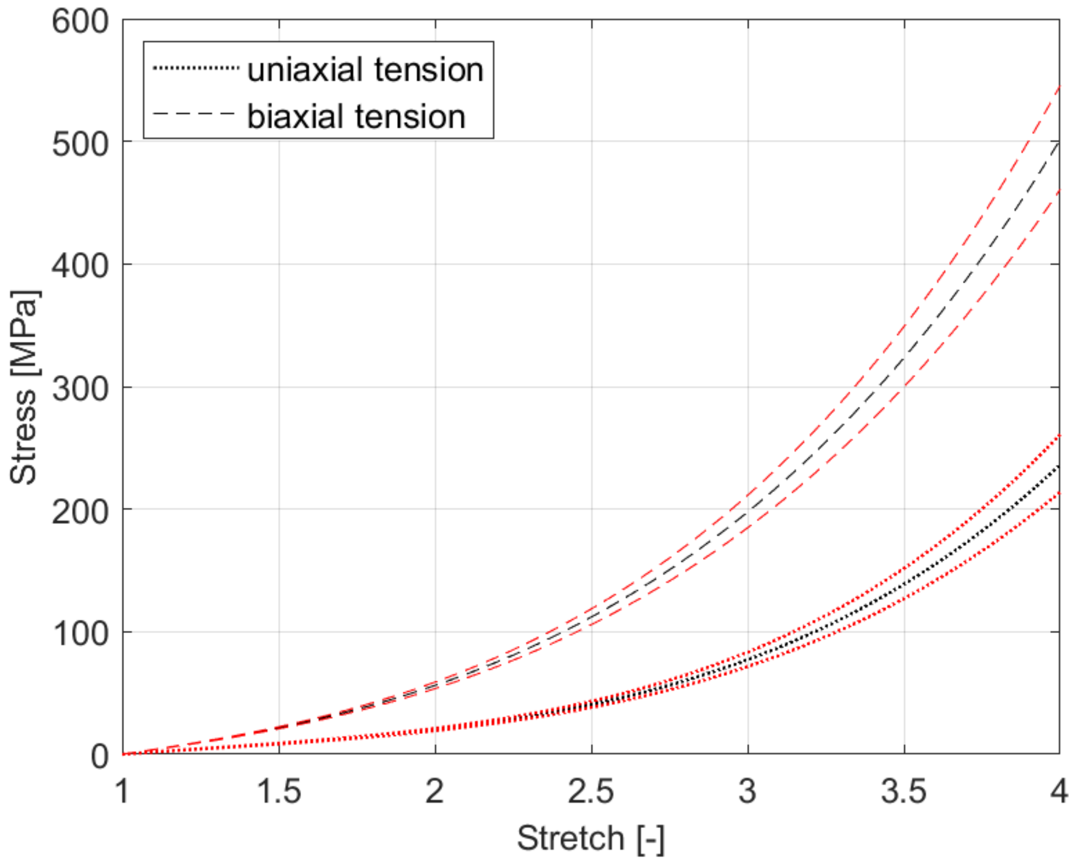
- Modulus of elasticity for glass mostly 70 GPa
- Values between 68 GPa and 74 GPa can be found in literature for soda-lime-silica float glass
- Variation of modulus of elasticity shows small effect on HIC



Robustness Evaluation – PVB Behavior

- PVB stress response modeled by Ogden's law by viscos terms (/MAT/OGDEN/)
- Parameters describe the relation between stretches λ and stress σ without viscos terms

- PVB influence by fitting stress versus stretch curves with constant factor for new parameters
- Stresses varied by a scale factor

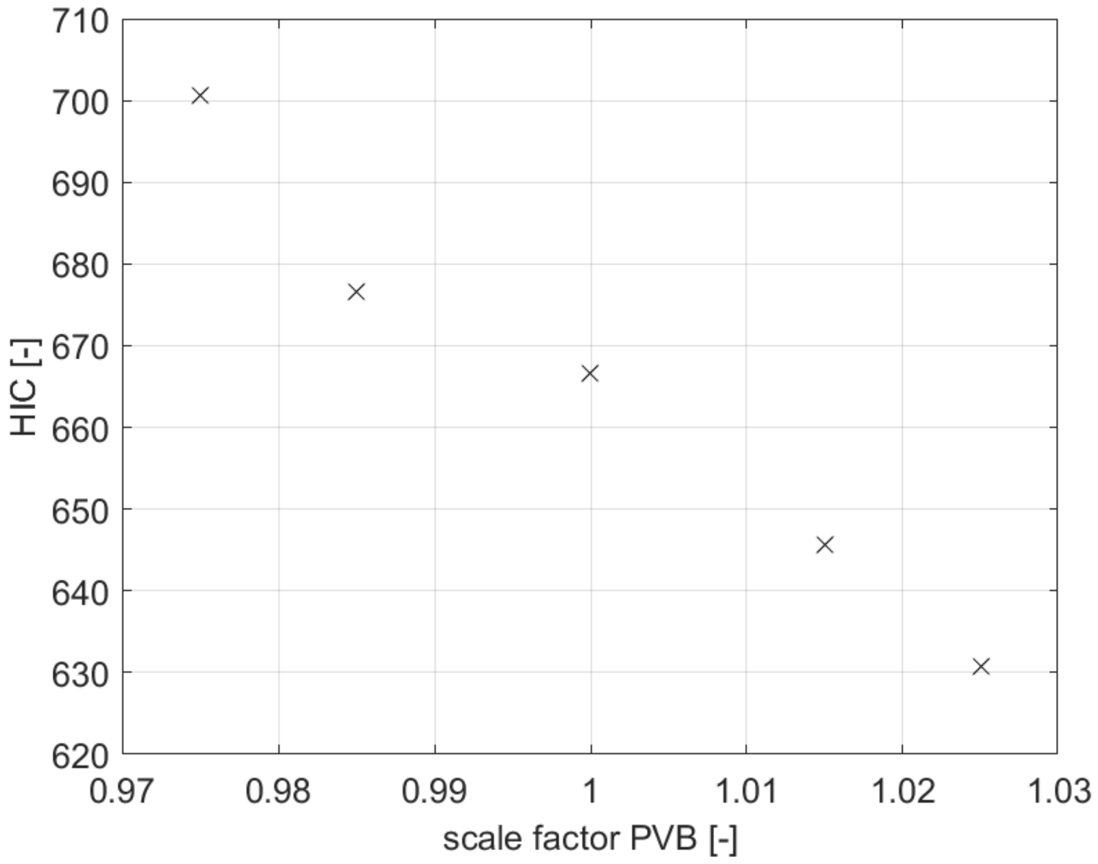


Robustness Evaluation – PVB Influence

- Increasing the stress reduces the HIC
- Degreasing the stress increases the HIC

- Deviation between both maximum deviations about 11 %

- Stiffer PVB reduces acceleration maximum
- Failure times t_1 and t_2 are nearly identical



Robustness Evaluation – Initial Cracks Lengths

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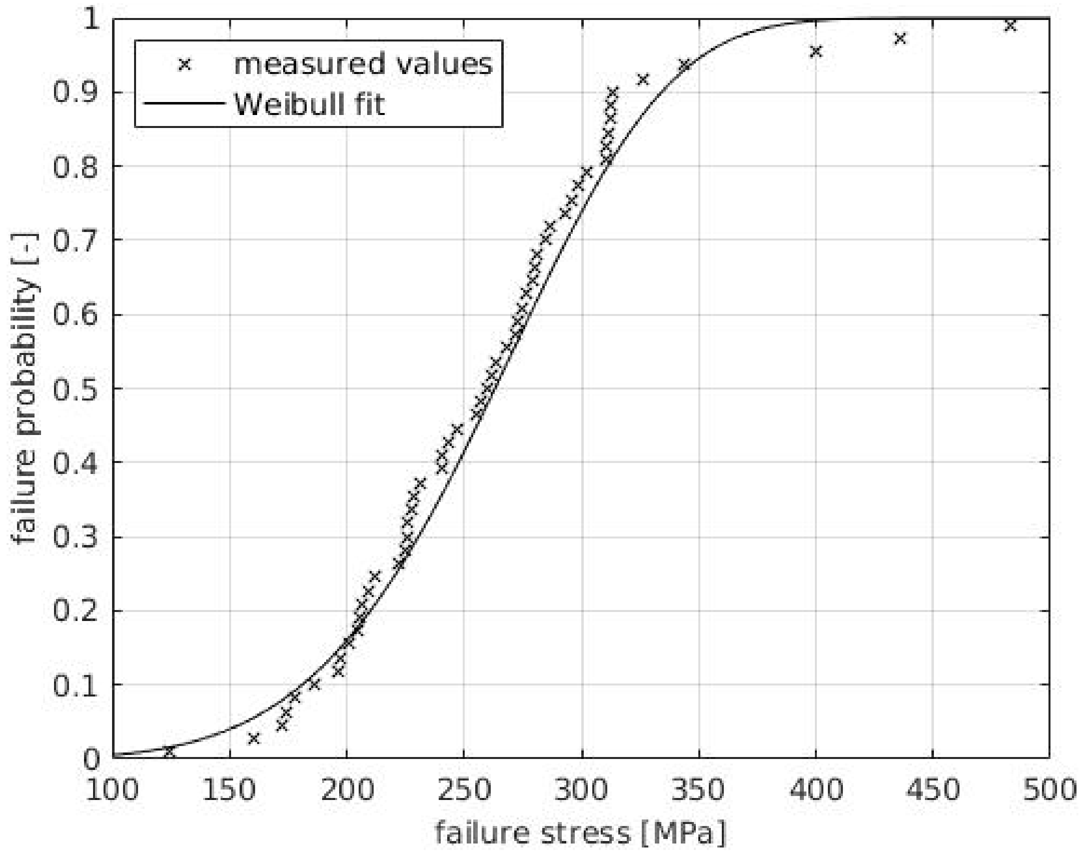
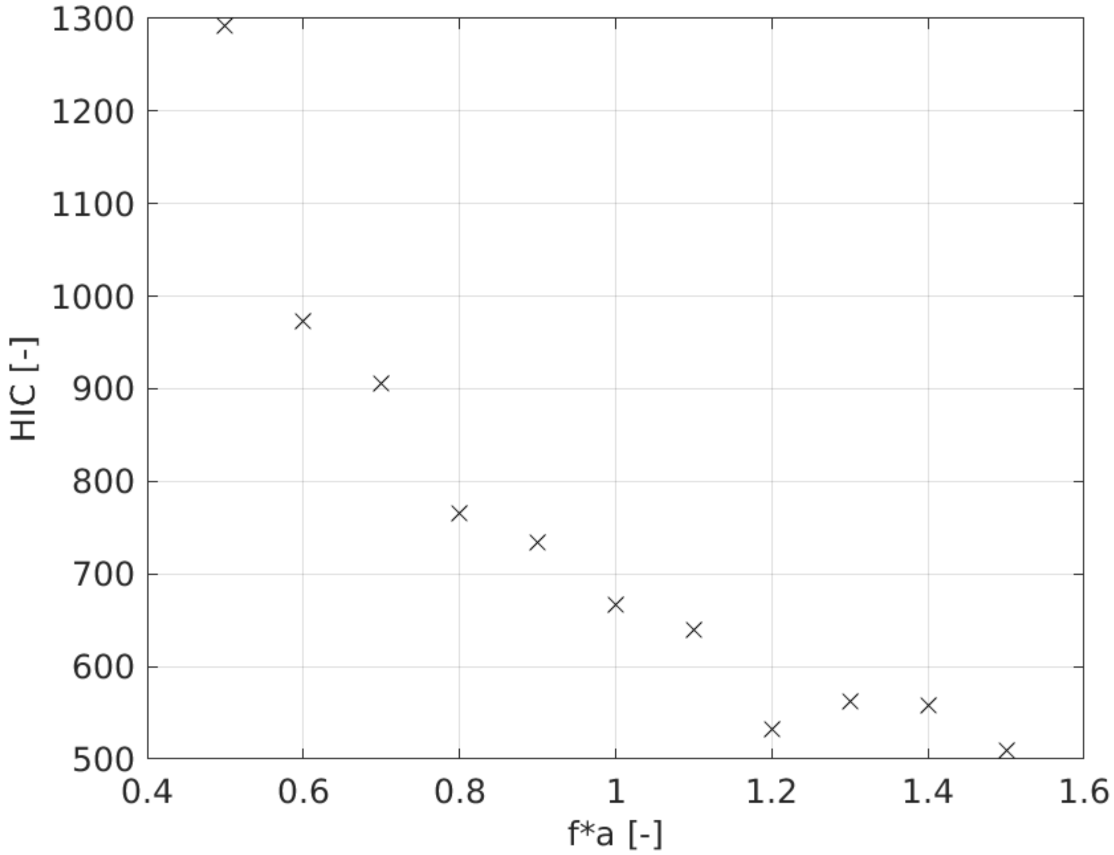
- /fail/alter is using initial crack lengths
  - Air = 1 µm
  - Edge = 30 µm
  - Foil = 0.4 µm
- Reality: Strength of glass is subjected to a large stochastic range
- Scaling of initial crack lengths by multiplying with a constant factor



Example for a two parameter Weibull distribution fit to experimental data. Test surface A_{Test} = 113.1 mm^2.

Robustness Evaluation – Initial Cracks Lengths

- Crack lengths show production influence
- Larger initial cracks = lower failure stress
- Scaling by multiplying with all three initial cracks with constant factor f between 0.5 and 1.5



- Crack lengths influences HIC significantly
- Initial cracks are statistically distributed

Robustness Evaluation – Thickness Glass

- Thickness of automotive windscreens varies depending on the car model
- Here the general influence of thickness is considered, not the manufacturing tolerances

Image source: www.auto-motor-und-sport.de

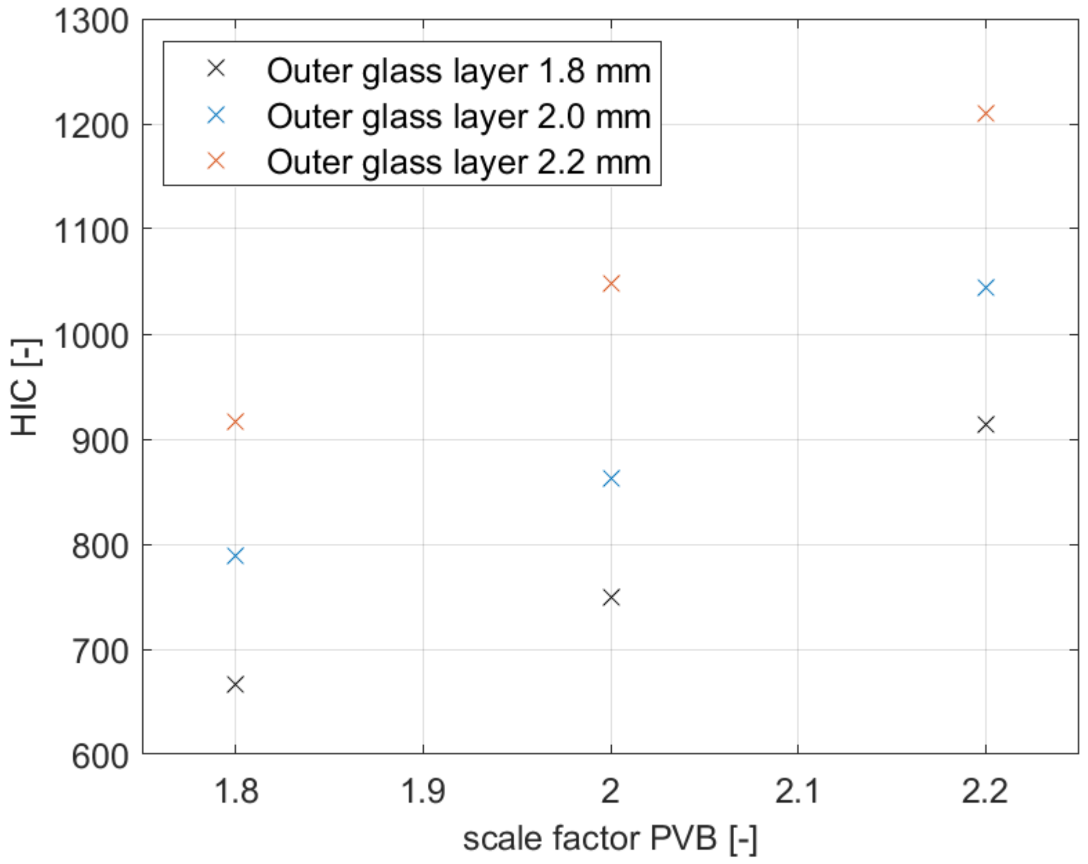
Mercedes C-Class windscreen:
2.1x0.78x2.1 mm (2015)

Image source: www.auto-motor-und-sport.de

Audi A3 windscreen:
1.8x0.76x1.8 mm (2018)

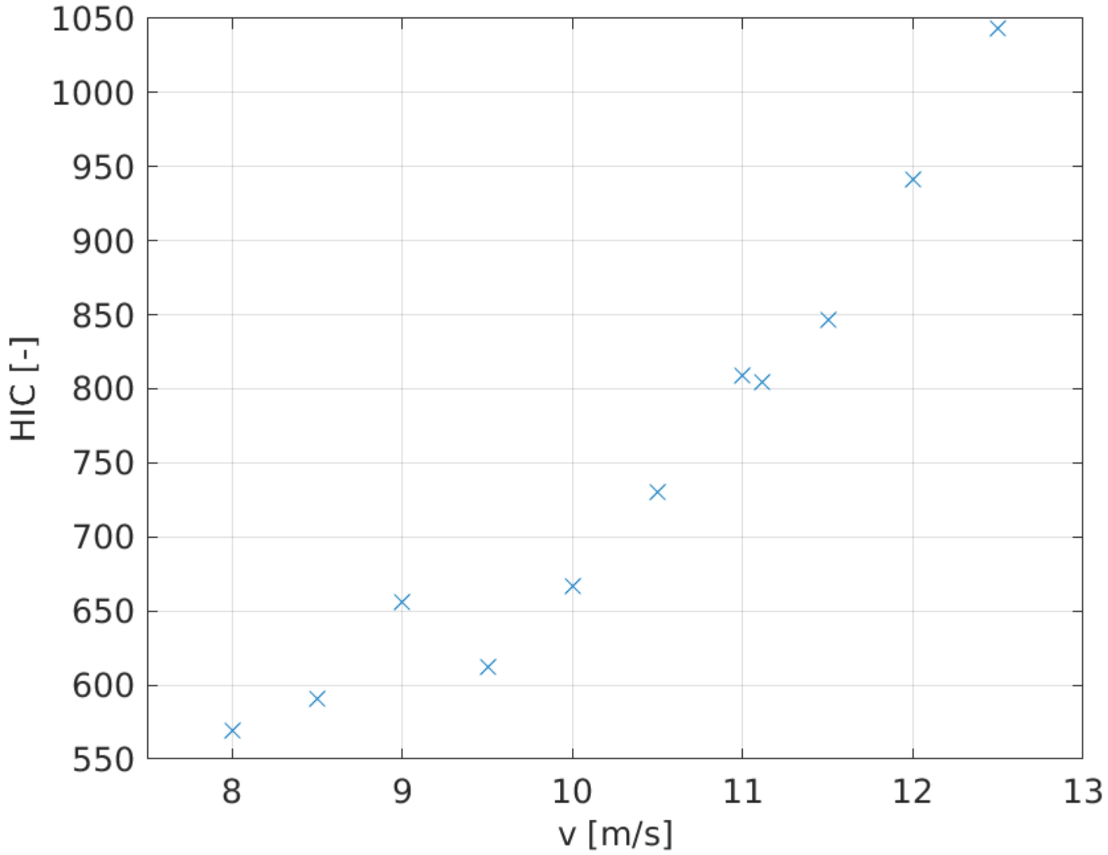
Robustness Evaluation – Thickness Glass

- Thickness of 1.8 mm and 2.2 mm in all combinations are considered
- Inner glass layer belongs to the interior side, outer glass layer to the exterior side
- HIC of 2.2x2.2 mm windscreen is 1.82 times higher than 1.8x1.8 mm windscreen



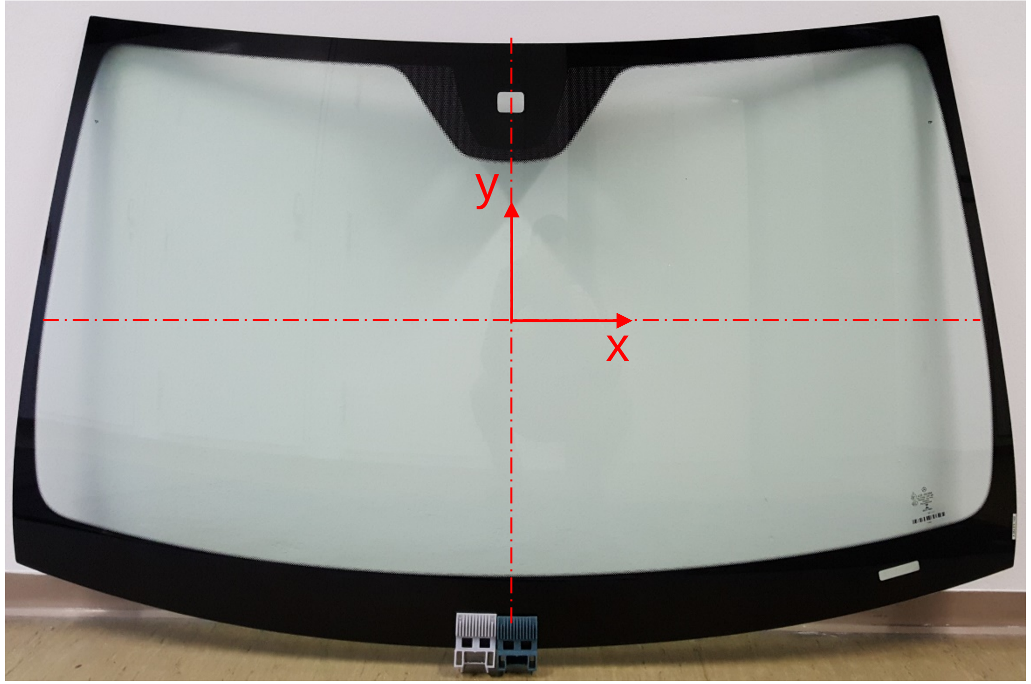
Robustness Evaluation – Impact Velocity

- Higher impact velocity obviously results in higher injury probability
- Impact velocity modified between 8 m/s and 12.5 m/s
- EuroNCAP impact velocity equals 11.11 m/s or 40 km/h
- As expected, HIC increases rapidly with growing impact velocity



Robustness Evaluation – Impact Location

- Impact position usually very accurate
- Positioning done by industrial robot
- Small deviation during free flight of impactor
- No systematic influence observable on HIC



x-Position [mm]	y-Position [mm]	HIC [-]
0	0	666.66
10	0	679.52
20	0	665.29
0	10	589.11
0	20	639.48
10	10	652.64
20	20	679.59

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Conclusions – Summary & Outlook

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- Relatively small influence on HIC by
  - Modulus of elasticity glass
  - Stress response PVB (stiffer PVB reduces HIC slightly)
  - Deviations in impact position are nearly without influence

- Of importance for the HIC value are
  - Thickness of the glass layers
  - Initial flaws (Origin of cracks lies in production/handling)
  - Larger initial flaws reduce the injury probability
  - Impact velocity

- Outlook
  - Statistical scattering of HIC through stochastic failure model for glass
  - Influence of robustness parameters on HIC distribution

Conclusions – Acknowledgement

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- Stochastic Fracture Behavior of Glass
- Fractographic Investigations
- Numerical Methods (FEM)

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