Robustness Evaluation of the Pedestrian Head Impact on an automotive Windscreen
Motivation & Aim

- 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
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


Robustness Evaluation Pedestrian Head Impact | Dynardo WOST 2020 | C. Brokmann, L. Aydin, S. Kolling
Agenda

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

Robustness Evaluation
  Influencing Parameters | C-Class Windscreen Analysis

Conclusions
  Summary & Outlook | Acknowledgement
Resulting acceleration [g] versus time [ms] during impact

Head Injury Criterion (HIC) to evaluate injury risk

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

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
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:

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

PVB interlayer
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
PVB stress response modeled by Ogden’s law by viscos terms (/MAT/OGDEN/)

- Parameters describe the relation between stretches $\lambda$ and stress $\sigma$ without viscos terms

- PVB influence by fitting stress versus stretch curves with constant factor for new parameters

- Stresses varied by a scale factor
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

➢ /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 $A_{\text{Test}} = 113.1 \text{ mm}^2$. 
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 influence HIC significantly

Initial cracks are statistically distributed
Thickness of automotive windscreens varies depending on the car model.

Here the general influence of thickness is considered, not the manufacturing tolerances.

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

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

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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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