Comparison of Steel and Aluminum Hood with same Design in View of Pedestrian Head Impact

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Comparison of Steel and Aluminum Hood with same Design in View of Pedestrian Head Impact

- Motivation
- Structural Stiffness Testing
- Pedestrian Safety Testing
- Summary
- Outlook
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Requirements for Automotive Hoods

- high global stiffness (bending, torsion)
- high local denting stiffness and strength (static and dynamic)
- dynamic stiffness (vibration behaviour)
- controllable deformation behaviour in frontal collision
- energy absorption at head impact
- minimized weight
- low costs
application of aluminum hoods because of smaller specific weight

application of steel hoods because of costs and properties

demand for comparing investigation (steel/aluminum)

actual series hood in two different material variants steel and aluminum for North America and Europe

comparison of the two material concepts according to
  - weight
  - structural behavior
  - pedestrian head impact
Structural Design of Analyzed Hoods

series hoods made of steel (USA) and aluminum (Europe) with nearly the same design of inner hood structure

www.fka.de

www.autosteel.org
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Stiffness Tests (e.g. Torsion)

- force [N]
- deflection [mm]

- original part steel
- original part aluminum
- spare part steel
- spare part aluminum

DOF_{1,2,3,4,6} = 0
DOF_3 = 0
Further Stiffness Tests

- **lateral stiffness**
  - $\text{DOF}_{1,2,3,4,6} = 0$
  - $\text{DOF}_3 = 0$

- **transversal stiffness**
  - $\text{DOF}_{1,2,3,4,6} = 0$
  - $\text{DOF}_3 = 0$

$\textbf{F}$

High bending stiffness results in reduced fluttering at high velocities and good accuracy in gap width to the fenders.

Great Designs in STEEL Seminar

www.autosteel.org
<table>
<thead>
<tr>
<th></th>
<th>steel hood</th>
<th>aluminum hood</th>
<th>comparison [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>hood mass</td>
<td>16.95 kg</td>
<td>9.00 kg</td>
<td>-46,9</td>
</tr>
<tr>
<td>thickness outer panel</td>
<td>0.68 mm</td>
<td>1.00 mm</td>
<td>+47,1</td>
</tr>
<tr>
<td>thickness inner panel</td>
<td>0.58 mm</td>
<td>1.00 mm</td>
<td>+72,4</td>
</tr>
<tr>
<td>lateral stiffness</td>
<td>97.17 N/mm</td>
<td>66.42 N/mm</td>
<td>-31,6</td>
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<tr>
<td>(absolute value)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>transversal stiffness</td>
<td>97.70 N/mm</td>
<td>63.81 N/mm</td>
<td>-34,7</td>
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<tr>
<td>(absolute value)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>torsional stiffness</td>
<td>2.58 N/mm</td>
<td>1.82 N/mm</td>
<td>-29,5</td>
</tr>
<tr>
<td>(absolute value)</td>
<td></td>
<td></td>
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</tbody>
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Investigation shows significantly higher stiffness of the steel hood in comparison to the aluminum hood but also significantly higher weight.
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Animation of Vehicle/Pedestrian-Crash

experimental testing with full body dummies of pedestrians is too cost-intensive

development of testing procedure which is based on subsystems for head, pelvis and leg areas of the pedestrian
Pedestrian Safety Directive of the European Parliament

**Head Impactor**

- **Child Head to Windscreen**
  - Phase 1 (2005): $v = 35 \text{ km/h}$, $m = 3.5 \text{ kg}$
  - Phase 2 (2010): $v = 35 \text{ km/h}$, $m = 4.8 \text{ kg}$
  - 2/3: HIC = 1000
  - 1/3: HIC = 2000

- **Adult Head to Windscreen**
  - Phase 1 (2005): $v = 35 \text{ km/h}$, $m = 3.5 \text{ kg}$
  - Phase 2 (2010): $v = 35 \text{ km/h}$, $m = 4.8 \text{ kg}$
  - No limit

**Upper Leg Impactor**

- Phase 2 (2010): $v = 40 \text{ km/h}$, $m = 4.8 \text{ kg}$
  - HIC = 1000

**Lower Leg Impactor**

- Phase 1 (2005): $v = 40 \text{ km/h}$, $m = 13.4 \text{ kg}$
  - $\varphi_{\text{knee}} = 21^\circ$
  - $\tau_{\text{knee}} = 6 \text{ mm}$
  - $a_{\text{knee}} = 200 \text{ g}$

- Phase 2 (2010): $v = 40 \text{ km/h}$, $m = 13.4 \text{ kg}$
  - $\varphi_{\text{knee}} = 15^\circ$
  - $\tau_{\text{knee}} = 6 \text{ mm}$
  - $a_{\text{knee}} = 150 \text{ g}$

**Forces and Moments**

- $F_{\text{Sum}} = 5 \text{ kN}$
- $M_b = 300 \text{ Nm}$

**Kinderkopfprüfkörper**

- $v = 40 \text{ km/h}$
- $m = 4.8 \text{ kg}$
- $E_{\text{kin}} = 295 \text{ J}$
- HIC = 1000

**Erwachsenenkopfprüfkörper**

- $v = 40 \text{ km/h}$
- $m = 2.5 \text{ kg}$
- $E_{\text{kin}} = 1000 \text{ J}$

**Oberschenkeprüfkörper**

- $v = 40 \text{ km/h}$
- $m = 2.5 \text{ kg}$
- $E_{\text{kin}} = 154 \text{ J}$

**Rechenkörpfe**

- $v = 40 \text{ km/h}$
- $m = 3.5 \text{ kg}$
- $E_{\text{kin}} = 825 \text{ J}$

**Kinderkopfprüfkörper**

- $v = 35 \text{ km/h}$
- $m = 4.8 \text{ kg}$
- $E_{\text{kin}} = 2000 \text{ J}$
- 2/3: HIC = 1000
- 1/3: HIC = 2000

**Erwachsenenkopfprüfkörper**

- $v = 40 \text{ km/h}$
- $m = 4.8 \text{ kg}$
- $E_{\text{kin}} = 1000 \text{ J}$

**Oberschenkeprüfkörper**

- $v = 40 \text{ km/h}$
- $m = 13.4 \text{ kg}$
- $E_{\text{kin}} = 150 \text{ J}$

**Kinderkopfprüfkörper**

- $v = 35 \text{ km/h}$
- $m = 13.4 \text{ kg}$
- $E_{\text{kin}} = 2000 \text{ J}$
- 2/3: HIC = 1000
- 1/3: HIC = 2000
Definition of Head Impact Areas
(Marking of the Vehicle)

- Hood leading edge reference line
  - 600 mm at 50°

- Hood side reference line
  - 45°

- Hood rear reference line

- Wrap around distance
  - (1,000 mm for child, 1,500 mm for adult)
Definition of the Impact Areas

determination of the impact areas for adult head and child head and further partitioning in each 3 segments
in each of the 6 segments 3 critical impact points are chosen

critical impact points result from the available package below the hood

the coordinates are measured in relation to the reference point
9 tests each are executed with the adult and the child head impactor (total 36 tests)

documentation of the results by deceleration pulse, HIC, $a_{3ms}$, $a_{max}$, high-speed-videos and digital fotos of plastic hood deformation
Deformation Behaviour
Child Head Impact M2

Ch-M-2

aluminum (HIC = 785)  steel (HIC = 1.278)

- bigger window for HIC calculation in aluminum version
- adequate deformation travel
- higher acceleration peak for steel version
- no significant secondary impact takes place
- 15-20 % more deformation travel for aluminum version

higher HIC-values for steel version
Ah-L-1

aluminum (HIC = 1.035)  
steel (HIC = 869)

- nearly equal windows for HIC calculation
- higher first acceleration peak for steel version
- higher secondary acceleration peak for aluminum version
- higher HIC-values for aluminum version
Plastic Hood Deformation at Adult Head Impact L3

Ah-L-3

outer hood view

inner hood view

steel

aluminum

- relatively small deformation because of impact on suspension strut dome
- slightly bigger local deformation for aluminum hood
in 13 of 18 cases the steel hood had a better performance for the HIC.
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Summary

- Analysis of steel and aluminum with nearly identical design under the aspects structural stiffness and pedestrian safety.

- Steel hood shows better stiffness values combined with significantly higher weight.

- Most of the determined HIC values are as expected clearly above the HIC-limit of 1.000, because the vehicle was not constructed explicit for good pedestrian safety.

- Significant influence of the structure below the hood and available free deformation travel, comparatively small material influence.

- Comparison of 18 head impact points (steel vs. aluminum) results in smaller injury severity for the steel hood in 13 points.

- Constructive optimization of the hood for both materials will lead to a reduction of the injury severity.
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Development of a Pedestrian-Friendly Hood
- Use of Numerical Optimization -

1. topography and topology optimization

2. draft versions

3. optimised inner panel
Development of a Pedestrian-Friendly Hood
- Benchmark of the HIC-Value -

- Child head area
- Adult head area

<table>
<thead>
<tr>
<th>HIC</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 700</td>
<td>Green</td>
</tr>
<tr>
<td>700-1000</td>
<td>Yellow</td>
</tr>
<tr>
<td>1000-1500</td>
<td>Blue</td>
</tr>
<tr>
<td>&gt;1500</td>
<td>Red</td>
</tr>
</tbody>
</table>

Optimised vs Series
Development of a Pedestrian-Friendly Hood
- Method to Optimize the HIC-Value -

- child head impactor
- glue
- hood outer panel
- hood inner panel
- rigid wall (e.g. engine block)

\[ \Delta g \]
\[ \Delta h \]

60 mm

\( t_{\text{inside}} \quad t_{\text{outside}} \)