Aluminium - Werkstoff für den Automobilbau

Jürgen Hirsch
Hydro Aluminium R&D Bonn
Aluminium - Werkstoff für den Automobilbau
Aktuelle Entwicklungen und Perspektiven für den Einsatz von Aluminium-Legierungen im Fahrzeugleichtbau

- Hydro – Europas integrierter Aluminium Konzern
- Einleitung, Motivation für den Automobil-Leichtbau
- Aluminium Konzepte für Automobile
  - State of the Art : Gußbauteile, Strangpress-Profile, Bleche in :
    Antriebsstrang, Struktur, Achsträger, Karosserie u.a.
  - Aktuelle Legierungsentwicklungen
- Leichtbau-Projekte :
  "Multi-Material Design"
- Zusammenfassung und Ausblick
Hydro Aluminium – Europas integrierter Aluminium Konzern
Hydro, a resource-rich, global aluminium company with robust positions across the value chain

- Global provider of alumina, aluminium and aluminium products
- Leading businesses along the value chain: raw materials, energy, primary metal production, aluminium products and recycling
- 13,000 employees involved in activities in more than 50 countries
  - Market capitalization ~NOK 75 billion
  - Annual revenues ~NOK 65 billion
- Included in Dow Jones Sustainability Indices and FTSE4Good
We serve a wide range of applications

**Litho**
- Plain strip and sheet for offset printing plates

**Packaging & building**
- Plain and lacquered strip for cans and other packaging containers
- Plain and converted foil for flexible packaging and technical applications
- Plain and lacquered strip, sheet and plate for architecture: Facades, roller shutters, etc.

**Automotive & heat exchanger**
- Plain and cladded strip and sheet for cars, transport and heat exchanger systems

**General engineering**
- Plain, anodised and cladded strip and sheet general engineering, solar technology and special industry
2 Motivation für den Automobil-Leichtbau
**Motivation**

Effect of the Vehicle Mass

Power demand of a vehicle

\[ P = (e_i \cdot m_v + m_{Ad}) \cdot a \cdot v + (m_v + m_{Ad}) \cdot g \cdot \sin(\alpha_g) \cdot v + (m_v + m_{Ad}) \cdot g \cdot \cos(\alpha_g) \cdot f_R \cdot v + 0,5 \cdot p_A \cdot c_w \cdot A \cdot (v - v_w)^2 \cdot v \]
CO2 emission targets across the world

Source: EAA brochure “Aluminium in Cars”
Aluminium content per car

- S1 - A/B segment mini/small cars
- S2 - C segment medium cars (small family car)
- S3 - D segment large cars (large family cars)
- S4 - E segment executive cars (executive car)

Average kg of Aluminium

Source: Ducker report / EAA
Aluminium relative and absolute weight savings and market penetration in automotive applications

<table>
<thead>
<tr>
<th>PART</th>
<th>RELATIVE WEIGHT SAVING</th>
<th>ABSOLUTE WEIGHT SAVING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine and transmission parts</td>
<td>50%</td>
<td>70 kg</td>
</tr>
<tr>
<td>Chassis and suspension parts</td>
<td>40%</td>
<td>70 kg</td>
</tr>
<tr>
<td>Hang-on parts</td>
<td>30%</td>
<td>40 kg</td>
</tr>
<tr>
<td>Wheel rims</td>
<td>20%</td>
<td>10 kg</td>
</tr>
<tr>
<td>Bumper systems</td>
<td>10%</td>
<td>10 kg</td>
</tr>
</tbody>
</table>

Source: EAA brochure “Aluminium in Cars”
Aluminium: “Stronger, tougher and more fuel efficient”

The car industry embraces aluminium


2) http://www.teslamotors.com/models/features#/performance

JAGUAR LAND ROVER

“The use of aluminium in an automotive application brings many benefits in terms of weight savings, improved fuel efficiency, lower emissions, increased crash safety and even better vehicle dynamics” 1)

TESLA

“The Model S body is a state-of-the-art, aluminum-intensive design. Weight-saving benefits make aluminum a natural choice” 2)

FORD

“Aluminium is stronger, tougher, and more fuel efficient than steel”
Ford CEO Alan Mulally

“The F-150 establishes aluminum as a primary choice for mainstream auto use”
Automotive News

(12) Prof.Dr.-Ing. Jürgen Hirsch – DGM - Werkstoffwoche 14.-17.09.2015 Dresden
State of the Art:
Gußbauteile, Strangpress-Profiles, Bleche in:
Antriebsstrang, Struktur, Achsträger, Karosserie u.a.
Aluminium castings in Engine Blocks and Cylinder Heads

1,2 Liter TDI - Engine / VW Lupo
Aluminium castings with high integrity
Extrusions for Bumpers & Crash Boxes

Front bumper system designed for high energy absorption with low weight

similation
Strangpressprofile im Automobilbau

Seitlicher Dachrahmen in „IHU“-Technologie

- Reduzierung Bauteile durch Entfall Fügetechnik
- Variabler Querschnitt herstellbar
- Kostenreduktion durch Bauteil-Substitution
- Verbesserung Formlinie (Reduzierung Toleranzen)

Multifunktionales Profil „Längsträger Radhaus“

- Größtes Al-Strangpressprofil für Karosserieanwendungen (umschriebener Kreis ca. 420mm)
- Wanddicken 3,0 - 5,5mm
- Beinhaltet Befestigung für Querlenker und Stabilisator
- Form, Rippen und Legierung für Crashverhalten optimiert
SoTA BIW: Extrusion intensive design

The **Body in White** (BIW) – seen as one component – is the heaviest part of a conventional (steel) car with a share of 25 to 30% of the complete car's weight, depending on options installed, engine size, and integrated safety features.

**Aston Martin Vanquish**
- Model Year: 2001
- Volume (Cars/year): 350
- Mass of BIW: 145 kg (excluding closures/outer skins, as displayed)
- Extrusion: 40 parts, 100 kg
- Casting: none
- Sheet: 40 parts, 45 kg
- Joining methods: rivets and adhesive

**BMW Z8 Roadster**
- Model Year: 2000
- Volume (Cars/year): 2,500
- Mass of BIW: 300 kg
- Extrusion: 86 straight parts, 24 bent parts
- Casting: none
- Sheet: 290 parts
- Joining methods: MIG welding and rivets (1,000 pcs)
SoTA BIW:

**Space Frame**

**Audi A 8 (D3, 2002)**
- Model Year: 2002
- Volume (Cars/year): scheduled 25.000
- Mass of BIW with closures: 277 kg
- Extrusion: 59 parts, 61 kg
- Casting: 31 parts, 39 kg
- Sheet: 170 parts, 177 kg
- Joining methods: Rivets (2400), MIG, Laser, Laser-Hybrid welds, Roll-folding, adhesive

**Jaguar XJ 2002**
- Model Year: 2002
- Volume (Cars/year): scheduled 30.000
- Mass of BIW: 295 kg
- Extrusion: 22 parts, 21 kg
- Casting: 15 parts, 15 kg
- Sheet: 273 parts, 259 kg
- Joining methods: adhesive, rivets (3,000 pcs), clinches, MIG

**Stamped Sheet Monocoque**
Aluminium Sheet Applications

**Chassis**
- Reduced unsprung mass → comfort
- Excellent corrosion resistance (unpainted)
- AlMg3.5Mn (Hydro 61/30 (IK))
- Hydro 5918-E improved strength

**Structure**
- Better weight distribution → improved driving dynamics
- High energy absorption during crash
- AlMg3.5Mn (Hydro 61/30 (IK))
- Hydro 5918-E with improved strength

**Car Body**
- High dent resistance
- Excellent corrosion resistance
- AlSi1.2Mg0.4 (Hydro 6016-E)
- AlMg4.5Mn0.4 (Hydro A63/44)
Aktuelle Legierungsentwicklungen
EN-AW 5xxx and 6xxx series Alloys in their Competition for Car Body Sheets
Hydro’s forming optimised AA5182 variant

High formability, good corrosion resistance

- Established alloy type: AA5182
- Door inner panels with requirements on
  - Strength
  - Stiffness
- Good corrosion resistance (IGC)
- High formability to allow for:
  - => integrated window frame
  - => large depth of draw

(examples presented by BMW at ACI Insight Ed. 2010 ; Castle Bromwich)
Hydro’s forming optimised AA5182 variant

High formability, good corrosion resistance

- Improved formability

![Biaxial flow curve (bulge test)](image)

- Without negative impact on corrosion resistance

![IGC Test](image)

![Successful press trial](image)
Al-Mg (AA5xxx) alloy range
Entwicklung hoch-Mg-haltiger 5xxx Legierungen; AlMg5+

Höhere Festigkeit bei gleichzeitig höherer Umformbarkeit!
Al-Mg+ for Car Parts (Simulation)

Standard: AlMg4.5Mn0.4

Average + 31% improvement

New: AlMg6.5

Distance to failure (="1")
New age hardening Al-Mg-Si Alloy Variants: Higher Strength and Faster Aging Characteristics

Higher Strength AA6070

Faster Aging AA6016
Hydro’s new alloy HA 6016-X
R&D forming lab results

- core alloy w/o layer
- HA 6016-X
- validation
Leichtbau-Projekte:

"Super Light Car"
Aluminium for Automotive Applications

- Fuel consumption - CO₂ emissions - EU regulations
- Light-weighting (besides Drivetrain, Aerodynamics, Rolling)
- New advanced Multi Material “MM” solutions:
  - new steel grades (high strength, hot forming)
  - Polymers/plastics (FRPs, LFT, RTM)
  - Magnesium (HPDC, sheet, extrusions)
  - Aluminium (HPDC, sheet, extrusions)
Mainly advanced high strength steel application, their combination (TWB, TRB patchwork, light materials, etc) and relative technologies (cold and hot stamping, hydroforming, roll forming, etc.); light alloys or polymers only where it is possible to guarantee additional functions.

**STEP 2: development of innovative vehicle architectures**

- Novel vehicle architectures
  - functional modularity
- “MM” Multimaterial design
- “Green” design

**Design and Material Usage Trends**

**STEP1: incremental approach (re-engineering of product & process)**

Mainly advanced high strength steel application, their combination (TWB, TRB patchwork, light materials, etc) and relative technologies (cold and hot stamping, hydroforming, roll forming, etc.); light alloys or polymers only where it is possible to guarantee additional functions.

- Light alloys (Al/Mg) or hybrid solution for chassis or mobile parts
- UHSS laser welding, structural adhesive bonding
- Thermoplastics for external panels and internal structures
- Impact

**CAFE 2008**

**CAFE 2015**

**Weight saving [kg]**

**Specific costs [€/Δkg]**

- Carbon, Kevlar composites for BIW
- Al for chassis
- New BIW and chassis architecture multi-material approach (Steel, Al, Mg, thermoplastics)
Beyond SoTA: the SLC Project

Sustainable Production Technologies of Emission Reduced Light weight Car concepts: SuperLIGHT-Car

**Motivation**

- Weight reduced vehicle structure suitable for large series productions
- Development of economically producible multi-material vehicle structures
- Pre-competitive technology screening (EU-Project)
- Lightweight car body contributes to a reduction in CO$_2$ emissions and fuel consumption
- Reduction of fuel consumption as a customer benefit

**Objective**

- Reference BIW\textsubscript{VW350} 280 kg; Objective BIW\textsubscript{SLC} 196 kg
- Weight reduction of body structure: $\geq 35\%$ ($\geq 100$ kg)
- Cost reduced multi-material manufacturability
- High volume capability
- Lightweight part costs: $\leq 7-8$ €/kg
- Fulfilling automotive requirements (crash, static …) for today’s mass-produced vehicle structures made from steel
SLC Project, Technology development

New forming technology development, up-scaling of most promising and improving of existing:

- Steel-steel (hot stamping & press hardening)
- Al & Mg warm & sheet forming technologies
- Al & Mg HPDC for complex structural parts
- Al & Al-steel TWB’s for crash-beams and side inner panels
- RTM high production rate technologies
- LFT reinforced application production technology
- Joining and assembling for multi-material high production BIW
## SLC Project: 3 basic SLC-concepts

### Steel intensive

<table>
<thead>
<tr>
<th>Weight reduction:</th>
<th>55kg (20%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additional costs:</td>
<td>&lt; 2,5 €/kg</td>
</tr>
</tbody>
</table>

**Highlights:**
- Strut tower in **austenetic steel**
- Tunnel in **hot-formed steel**
- Bodyside and B-pillar in **dualphase-steel**
- Roof in **steel/polymer compound**
- Fender in **steel/polymer compound**

**Motivation:**
- weight reduction with increased utilisation of **high strength steels**

### ULBC

<table>
<thead>
<tr>
<th>Weight reduction:</th>
<th>74 kg (27%)</th>
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<tr>
<td>Additional costs:</td>
<td>&lt; 5 €/kg</td>
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</table>

**Highlights:**
- Longitudinal rail in **austenetic steel** tailored welded blanks
- Suspension-strut mount as **Al-diecast**
- Tunnel in **austenetic steel**
- Rear wheelhouse in **Al-diecast**
- Inner B-pillar in **Al-diecast**
- Roof in **Al-sheet**

**Motivation:**
- multi-material design weight reduction
- steel in the loading paths
- lightweight design materials such as aluminium for the front end and roof
- cast parts including high-integration

### SLBC

<table>
<thead>
<tr>
<th>Weight reduction:</th>
<th>115 kg (38%)</th>
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</thead>
<tbody>
<tr>
<td>Additional costs:</td>
<td>&lt; 10 €/kg</td>
</tr>
</tbody>
</table>

**Highlights:**
- Longitudinal rail in **Trip800** tailored welded blanks
- Strut tower as **Mg-diecast**
- Floor panel in **Al- and Mg-blank**
- Wheelhouse and rear longitudinal rail in **Al-blank**
- Inner B-pillar in **hot-formed steel**
- Roof in **Mg-sheet**

**Motivation:**
- Priority 1: Weight reduction through multi-material design
- Priority 2: Part count and cost targets

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**NOTE:** structural performance not equal to reference for all concepts

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Final SLC Body concept

SLC Body in white weight: 180kg

Material distribution:
Aluminium sheet
Aluminium casting
Aluminium extrusion
Hot formed Steel
Magnesium sheet
Magnesium casting
Fibreglass reinforced

Mass distribution:
Aluminium: 94 kg (53%)
Steel: 66 kg (36%)
Magnesium: 11 kg (7%)
Plastics: 7 kg (4%)

Structural weight [kg]

Reference SLC
SLC Concept

Alu: 64 Vol.%

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SLC side panel produced from Al TWBs
SLC Project, Technology development

New materials development - BIW (aluminium alloys):

- Crash alloy for structural application (6xxx and 7xxx alloy with high energy absorption and excellent crash characteristics)
- Roof alloy, with high strength 6xxx alloy with fast PBR
- Aluminium sheet for body side 6xxx alloy
Design Study – Front crash & stiffness

A comparison of the predicted EuroNCAP frontal impact crash metrics was made for each front end option, together with the predicted BIW stiffness and modes:

- Comparison of predicted footwell intrusions
- Comparison of frequency of predicted modes
- Comparison of predicted pulse
The SLC bridge software tool
SLC – Applied Joining technologies

- Structural bonding (98m)
- Cold metal transfer (15m)
- Arc welding (6.5m)
  - Highspeed Mechanical joining (Rivtac/Altracs 130x)
  - Riveting & Self piercing Riveting (2000x)
  - Resistance spot welding (300x)
  - Flow-drill screwing (6x)

Adhesives:

<table>
<thead>
<tr>
<th>Family</th>
<th>Type</th>
<th>Application</th>
<th>Suggested brand</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>High structural ad</td>
<td>Epoxy</td>
<td>Metal-Metal</td>
<td>Betamate 1496/1482</td>
<td>100%</td>
</tr>
<tr>
<td>Structural ad</td>
<td>Epoxy</td>
<td>Metal-Metal</td>
<td>Betamate XW1185</td>
<td>50%</td>
</tr>
<tr>
<td>Struct / Elastic</td>
<td>Polyur.</td>
<td>Metal-Plastic</td>
<td>Betaseal 1502</td>
<td>50%</td>
</tr>
</tbody>
</table>
Assembling layout scheme with warehouses areas, unloading points and material flows for mass production

**SLC assembly rate: 1 minute!**
Lightweight design and CO₂ emissions within product life cycle

Vehicle Production

Vehicle Usage
[Road performance in km]

Vehicle Recycling

Greenhouse gas [kg CO₂-Aq.]

→ Intelligent lightweight design integrates the complete product life cycle

Quelle: K-EFU

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SLC Concept Summary:

- SLC BIW reaches weight reduction in a cost increment of 7-8 €/kg saved*.
- Final concept status: structure performance equal to reference body structure
- SLC weight summary (VW Golf V):
  - Total BIW Weight: 181 kg
  - Total BIW Weight saved: 35%
- Manufacturing & Assembling technologies feasible for high volume production ratio
- Total production volume: 225,000 car/year
- Prototyping exercise (presented at the SLC conference in Wolfsburg, May 26th 2009)

(*) part manufacturing cost difference vs. reference (without assembly)
Leichtbau-Projekte
"Light e-Body"
das Voll-Aluminium Konzept
Full Aluminium Concept Design
Drivetrain

• Battery system
• Motor with Power electronics
Full Aluminium Concept Design
Body in White
Full Aluminium Concept Design
Body in White – Overview

- Extrusions
- Bended extrusions
- Tailor Rolled Tube
- Hydroforming
- Cast nodes
BIW: B-Pillar Sheets

Thickness: 1.8 mm, 1.15 mm

Selected Material: AA5182 AlMg4,5Mn
Final Model Design
Battery System - Tailor Rolled Tube

- Tailor rolled tube battery crossmember
- Defined zone of deformation
Full Aluminium Concept Numerical Dimensioning
Euro NCAP – Pole Impact

Acceleration (CFC 60 filtered)

No critical Battery intrusion/deformation.
Full Aluminium Concept : Weight Reduction

• Conservative concept (Full Steel)
  • Body-In-White + Battery structure 314 kg
• Aluminium Concept
  • Body-In-White + Battery structure 199 kg

• Weight reduction Full Aluminium Concept 115 kg

• (Weight reduction of the Light-eBody Concept 68 kg)

• Secondary weight reduction is not considered
Zusammenfassung und Ausblick
Automotive drive demand for aluminium

40 years of uninterrupted growth – accelerating from 2015 to 2025

Aluminium content – pounds per light vehicle

**DUCKER WORLDWIDE:**
In 2015, aluminium penetration will reach the critical mass for an explosive period of growth from 2015 to 2025

In 2025, light vehicles will be the most important global market for aluminium.

Source: Ducker Worldwide, ‘2015 North American Light Vehicle Aluminium Content Study’
Zusammenfassung

Aluminium ist ein ideales Material für den effektiven Leichtbau im Fahrzeug. Es ermöglicht bis zu 50% Gewichtseinsparung im Vergleich zu existierenden Lösungen, ohne Einschränkung der geforderten Eigenschaften und der Sicherheit.

In Europa hat sich der Einsatz von Aluminium im Automobil heute weitgehend etabliert. Je Auto werden im Durchschnitt \( \sim 150 \text{kg} \) Aluminium verbaut – in Antrieb, Karosserie, Anhängeteilen und Struktur; als Gußteile, Bleche und Profile - mit steigender Tendenz.


Das SLC Projekt verifizierte dieses Konzept in einer optimierten Leichtbau-Karosserie eines etablierten Golf V und erreichte 35% Gewichtseinsparung bei Mehrkosten von 7,8\( \text{€} / \text{kg} \). Mit > 50% Gewichtsanteil im realisierten Prototype war Aluminium war der große Gewinner!
Acknowledgments

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1. “SLC” (Sustainable Production Technologies of Emission Reduced Light weight Car concepts) was funded by the EU under the 6th Framework Programme under Contract no.: 516465  More Info : www.superlightcar.com

2. “Light-eBody“ (Light and Ressourceefficient Electro-Car Body in Multimaterial Design) was funded by the BMBF under Contract n.: 03X3034D

3. “Full Aluminium Light-eBody“ (Aluminium Electro-Car Lightweight Design, Light eBody sides study ) was conducted by the fka Forschungsgesellschaft Kraftfahrwesen mbH Aachen, suported and fully funded by Hydro Aluminium corporate R&D  More Info :

co-workers: Schäfer, C.; Hirsch (PL), J.; Brinkman, (Hydro) and H.-J.; Hören, B/*.; Schulte, T./* fka
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