轻量化汽车用材料的解决方案
Material Solutions for Auto Lightweighting

2015 绿色制造—未来的钢铁与汽车国际研讨会
International Conference on Green Manufacturing
- the Future of Steel Automobile 2015

宝钢研究院
2015年11月17日
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1. 什么是汽车轻量化的最佳材料？
   What is the best Auto LW Material?

2. 先进高强钢对汽车轻量化的贡献
   AHSS Contributions for Lightweight

3. 先进高强钢家族
   Latest AHSS Family
Automotive and Technologies

1. 基础：材料
   Base: Materials

2. 载体：结构
   Platform: Structure

3. 性能、重量、成本
   Result: Performance/Mass/Cost
过去30年期间，汽车的质量增加了一倍。
Vehicle class comprehensive increase of the vehicle curb mass over the last 30 years up to 50%.

Source: WorldAutoSteel
1950年至2012年汽车安全法规与车祸死亡数据

Regulations v.s Traffic Deaths (1950 - 2012)

不同的碰撞和安全法规的制定降低了车祸死亡人数
Decreasing number of traffic deaths by publishing different crash and safety regulations

Source: WorldAutoSteel
What is the Public Request at Present

- Historically, increasing vehicle curb mass decreased the number of traffic deaths in the past.

- Today, the request is to reduce CO2 emissions with high safety requirements.

- The question is how to choose materials that are both strong, durable, safe, and environmentally friendly, while also being lightweight and cost-effective.
Density of main Auto Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Density [g.cm⁻³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic</td>
<td>1.1</td>
</tr>
<tr>
<td>Magnesium</td>
<td>1.7</td>
</tr>
<tr>
<td>CFRP</td>
<td>1.8</td>
</tr>
<tr>
<td>Aluminium</td>
<td>2.7</td>
</tr>
<tr>
<td>Steel</td>
<td>7.9</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>8</td>
</tr>
<tr>
<td>Copper</td>
<td>9</td>
</tr>
</tbody>
</table>

Light Materials

Heavy Materials
### Material Production GHG comparison for a functionally equivalent component - *example*

<table>
<thead>
<tr>
<th>Material</th>
<th>Mid-Range CO2e (kg CO2e)</th>
<th>Estimated Part Weight (kg)</th>
<th>Source: WorldAutoSteel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild Steel</td>
<td>2.3</td>
<td>100</td>
<td>230</td>
</tr>
<tr>
<td>Advanced High</td>
<td></td>
<td></td>
<td>173</td>
</tr>
<tr>
<td>Strength Steel</td>
<td></td>
<td></td>
<td>1106</td>
</tr>
<tr>
<td>Aluminum</td>
<td>16.5</td>
<td>67</td>
<td>2300</td>
</tr>
<tr>
<td>Magnesium</td>
<td>46.0</td>
<td>50</td>
<td>990</td>
</tr>
<tr>
<td>Carbon FRP</td>
<td>22.0</td>
<td>45</td>
<td></td>
</tr>
</tbody>
</table>
Auto Lightweighting Strategy

First Level: Decision Factors

Starting Point

Second Level: Decision Factors

Sensitive Factors LCA, Cost

Material Selection

Third Level: Decision Factors

3rd Priority

The right materials at the right places
Overview of Auto Materials

- 进高强钢 AHSS
- 铝合金 Aluminum
- 镁合金 Magnesium
- 碳纤维 CFRP

性能指标包括：密度 Density、强度 Strength、可回收性 Recycle、LCA、可焊接性 Weldability、延伸率 Elongation、可制造性 Manufacturability。
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3 先进高强钢家族
Latest AHSS Family
### A. Front Door

<table>
<thead>
<tr>
<th>Frame mass estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ m (kg) ]</td>
</tr>
<tr>
<td>[ = 10.144(Area , m^2)^{0.884} \times \begin{array}{c} \text{Steel} \ 1.43 \end{array} \times \begin{array}{c} \text{Alum} \ 1.00 \end{array} \times \begin{array}{c} \text{1.06 linkage regulator} \ 1.00 \end{array} \times \begin{array}{c} \text{cable} \ 1.03 \end{array} \times \begin{array}{c} \text{post} \ 1.00 \end{array} ]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Steel efficient design</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ m_{eff}(kg) = \frac{10.14(Area , m^2)^{0.884} \times 1.43 \text{Steel}}{1.12 \times 1.123} \times \begin{array}{c} \text{1.06 linkage regulator} \ 1.03 \end{array} \times \begin{array}{c} \text{if cable} \ 1.00 \end{array} \times \begin{array}{c} \text{if post} \ 1.00 \end{array} ]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Aluminum efficient design</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ m_{eff}(kg) = \frac{10.14(Area , m^2)^{0.884} \times 1.0 \text{Alum}}{1.0 \times 1.123} \times \begin{array}{c} \text{1.06 linkage regulator} \ 1.03 \end{array} \times \begin{array}{c} \text{if cable} \ 1.00 \end{array} \times \begin{array}{c} \text{if post} \ 1.00 \end{array} ]</td>
</tr>
</tbody>
</table>

\[ R^2 = 0.56, \quad \text{Standard Error} = 1.123 \]

Source: WorldAutoSteel.org
In the regression analysis, $R^2$ is the coefficient of determination, which shows the influence effect of variable $X$ to $Y$. $R^2 = 0$ to 1. The higher of $R^2$ value, the more effect $X$ to $Y$.

An $R^2$ value of 0.6 indicates that 60% variation in the data point values is accounted for by the chosen variables in the equation.

For $R^2$ less than 0.5, the mass efficient options should be further reviewed and engineering judgment should be applied to identify the designs for further study.

Source: WorldAutoSteel.org
**Case Study 1: Door Mass Comparison, Steel vs. AL**

Mass savings achieved at the component level often not realized at the system level based on 240 vehicles of A2Mac1 Euro & NA Database.

**Source:** WorldAutoSteel.org
适当有效的设计可使钢铝之间的重量差距大为减少。
The Table shows the mass saving potential of aluminum is significantly reduced when compared with the ‘efficient’ steel designs. This shows a good opportunity for automotive steel suppliers to exploit the features of the efficient steel designs to narrow the gap with aluminum.

<table>
<thead>
<tr>
<th>Vehicle Sub System</th>
<th>Average Designs</th>
<th></th>
<th>Effcient Designs</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Steel</td>
<td>Aluminum</td>
<td>Steel</td>
<td>Aluminum</td>
</tr>
<tr>
<td></td>
<td></td>
<td>%</td>
<td>Delta</td>
<td></td>
</tr>
<tr>
<td>Front Doors</td>
<td>16.26</td>
<td>11.34</td>
<td>-30%</td>
<td>12.92</td>
</tr>
<tr>
<td>Hood</td>
<td>13.48</td>
<td>8.12</td>
<td>-40%</td>
<td>10.42</td>
</tr>
<tr>
<td>Hatchback</td>
<td>11.40</td>
<td>8.14</td>
<td>-29%</td>
<td>8.65</td>
</tr>
<tr>
<td>Decklid</td>
<td>10.70</td>
<td>8.12</td>
<td>-24%</td>
<td>8.85</td>
</tr>
<tr>
<td>Liftgate</td>
<td>15.26</td>
<td>10.23</td>
<td>-33%</td>
<td>12.18</td>
</tr>
<tr>
<td>Wheel Rim</td>
<td>9.23</td>
<td>8.28</td>
<td>-10%</td>
<td>7.24</td>
</tr>
<tr>
<td>Rear Bumper</td>
<td>6.30</td>
<td>4.21</td>
<td>-33%</td>
<td>3.34</td>
</tr>
<tr>
<td>Front Bumper</td>
<td>6.21</td>
<td>4.26</td>
<td>-31%</td>
<td>2.70</td>
</tr>
<tr>
<td>Body Structure</td>
<td>348.3</td>
<td>240.7</td>
<td>-31%</td>
<td>305.7</td>
</tr>
<tr>
<td>Body Structure – FSV-AHSS</td>
<td></td>
<td>348.3</td>
<td>-31%</td>
<td>305.7</td>
</tr>
</tbody>
</table>

Source: WorldAutoSteel.org
物理上的和功能上的差异

使用高效钢质车身结构可以减小与铝制车身间的重量差距
Narrow margin in vehicle curb weights between vehicles using efficient steel body structures and aluminum body structures.

铝制
Efficient Aluminum

降低车身重量9.3%
Reduces Curb Weight by 9.3%

2.8% Gap

高效钢制
Efficient Steel

降低车身重量6.5% (目前)
Reduces Curb Weight by 6.5% (currently)

Steel is not such heavy like you think

Source: WorldAutoSteel.org
研究案例 2：宝钢BCB (Baosteel Car Body)
Case Study 2: Baosteel BCB

<table>
<thead>
<tr>
<th>车型 Model</th>
<th>重量 Weight</th>
<th>轻量化系数 Lightweight index</th>
<th>高强钢比例 Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCB</td>
<td>297.3</td>
<td>2.83</td>
<td>76.7%</td>
</tr>
<tr>
<td>BMW 3</td>
<td>301.3</td>
<td>2.66</td>
<td>70.0%</td>
</tr>
<tr>
<td>Mondeo</td>
<td>317</td>
<td>3.62</td>
<td>66.6%</td>
</tr>
<tr>
<td>S60</td>
<td>321.5</td>
<td>3.13</td>
<td>58.4%</td>
</tr>
<tr>
<td>Saab 95</td>
<td>395.4</td>
<td>4.33</td>
<td>62.6%</td>
</tr>
<tr>
<td>E class</td>
<td>408</td>
<td>2.95</td>
<td>76.8%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>指标 Index</th>
<th>项目目标 Target</th>
<th>设计值值 Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>重量 (kg)</td>
<td>300</td>
<td>297.3</td>
</tr>
<tr>
<td>HSS Proportion</td>
<td>70%</td>
<td>77%</td>
</tr>
<tr>
<td>零件数 (个)</td>
<td>350</td>
<td>309</td>
</tr>
<tr>
<td>Lightweight index</td>
<td>3</td>
<td>2.59</td>
</tr>
<tr>
<td>被动安全</td>
<td>五星</td>
<td>五星</td>
</tr>
</tbody>
</table>
Case Study 2: Baosteel BCB

- BCB white车身大量应用高强度材料，高强钢应用比例77.5%，镀锌板应用比例75%。
Large number of HSS is used and the ratio is more than 77.5%, and the proportion of galvanized sheet application is 75%.

- BCB白车身用材涵盖宝钢第一代、第二代和第三代汽车用钢，包括最新开发的1180QP、1500MS、950TWIP等新材料。
BCB materials includes 1st, 2nd and 3rd generation of automotive steels, and the latest developed materials, such as 1180QP, 1500MS, 950TWIP steel and so on.
### BCB的先进制造工艺
Advanced forming processes

<table>
<thead>
<tr>
<th>工艺</th>
<th>图示 parts</th>
<th>零件数量</th>
<th>重量比 weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>热冲压</td>
<td><img src="image" alt="Hot Stamping" /></td>
<td>9</td>
<td>8.69%</td>
</tr>
<tr>
<td>辊压</td>
<td><img src="image" alt="Roll Forming" /></td>
<td>3</td>
<td>3.33%</td>
</tr>
<tr>
<td>液压</td>
<td><img src="image" alt="Hydroforming" /></td>
<td>4</td>
<td>0.54%</td>
</tr>
<tr>
<td>VRB</td>
<td><img src="image" alt="Variable thickness rolled blanks" /></td>
<td>2</td>
<td>0.51%</td>
</tr>
<tr>
<td>TWB</td>
<td><img src="image" alt="TWB" /></td>
<td>8</td>
<td>7.12%</td>
</tr>
</tbody>
</table>

宝钢BCB集中体现了目前最先进的金属成形工艺技术，并通过高强减薄，实现整车性能不下降、车身轻量化的目标。

Based on Baosteel advanced forming technologies, hot stamping, hydroforming, roll forming, VRB sheet forming and TWB sheet forming technologies are used for BCB. By applying higher strength steels to reduce part thickness, vehicle performance is not reduced and lightweight body is gained.
Case Study 2: Baosteel BCB

- BCB white body大量应用高强度材料，高强钢应用比例77.5%，镀锌板应用比例75%。
  Large number of HSS is used and the ratio is more than 77.5%, and the proportion of galvanized sheet application is 75%.

- BCB white body用材涵盖宝钢第一代、第二代和第三代汽车用钢，包括最新开发的1180QP、1500MS、950TWIP等新材料。
  BCB materials includes 1st, 2nd and 3rd generation of automotive steels, and the latest developed materials, such as 1180QP, 1500MS, 950TWIP steel and so on.
● 轻量化材料、轻量化设计、轻量化工艺的集中体现
The perfect example for LW materials, LW design, and LW manufacturing processes
● 是一个钢铁企业对汽车轻量化的诠释
That is an understanding for auto lightweighting strategy by a steel maker
● 是一个对汽车轻量化重要贡献的一个典型案例
That is a typical solution for auto lightweighting purposes
Case Study 3: Front rail under diff. Solutions
Steel Solutions for Front Rail

Whole Vehicle Properties

成本 Cost

重量 Weight

整 车 性 能

BIW Properties

可制造性 Manufacturability

HSS方案
UHSS(a)方案
UHSS(b)方案
TWB(a)方案
TWB(b)方案
VRB方案
- 强度更高、成形性更好的先进高强钢和超高强钢
  More AHSS and UHSS with higher elongation and formability

- 拓扑优化设计促成同等性能条件下的最少材料使用
  Topology structure design for min material application and equal performance

- 近终的零部件结构（VRB，VRT，LWB，LWT，...）
  Net-shape or near net-shape design for parts and components
2-F (Fine Design and Fine Manufacturing) will be the trend of auto body and component lightweighting strategy.
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   Latest AHSS Family
### 第三代AHSS性能目标：Target 3rd Gen AHSS Properties

<table>
<thead>
<tr>
<th>类型/Type</th>
<th>屈服强度 YS/MPa</th>
<th>抗拉强度 TS/MPa</th>
<th>断后伸长率 A</th>
<th>均匀伸长率 Ag</th>
</tr>
</thead>
<tbody>
<tr>
<td>高强度，超高塑性</td>
<td>≥800</td>
<td>≥1200</td>
<td>≥30%</td>
<td>≥20%</td>
</tr>
<tr>
<td>High Strength, Exceptional Ductility</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>超高强度，高塑性</td>
<td>≥1200</td>
<td>≥1500</td>
<td>≥25%</td>
<td>≥8%</td>
</tr>
<tr>
<td>Exceptional Strength, High Ductility</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![BaoSteel QP Steel](#)

- 20% @ 1000 MPa
- 16% @ 1200 MPa
AHSS with balanced mechanical properties are preferred in development and application cases.
QP1180的应用提供一种热冲压用钢的替代方案，QP钢可以代替780MPa及以下级别UHSS实现轻量化。

- QP 1180 provides an alternative solution to PHS1500
- QP steels can be applied to those parts made by UHSS with 780MPa or lower grades for lightening
1st Generation of AHSS

- **DP**
  - CR: 500, 590, 780, 980, 1180
  - GI: 500, 590, 780, 980, 1180
  - GA: 500

- **MS**
  - CR: 1000, 1200, 1300, 1400, 1500, 1700
  - EG: 1200

- **TRIP**
  - CR: 590, 690, 780, 980, 1180
  - GI: 590, 690, 780, 980
  - HR: 780

- **CP**
  - CR: 590, 780, 980, 1180
  - GI: 590, 780, 980
  - HR: 780

**Key Color Codes:**
- **Black:** Commercialized
- **Blue:** Trial production
- **Red:** Under Developing

**Materials:**
- Bumper, HC700/980DP (1.6mm)
- Rear bumper, HC700/980MS (1.6mm)
- B-piller reinforcement, HC420/780TR (1.8mm)
- Control arm, CP800-HR (3.2mm)
New AHSS

AHSS = Inexpensive way to reduce weight

- **Q&P (DDQ)**
  - CR
    - 980
    - 1180
    - 1300
  - GI
    - 980
    - 1180
    - 1300
  - 20% @ 1000 MPa

- **Mn-TRIP (EDDQ)**
  - CR
    - 980
    - 1180
  - GI
    - 980
    - 1180
  - 30% @ 1000 MPa

- **TWIP (SEDDQ)**
  - CR
    - 980
    - 1180
  - GI
    - 980
    - 1180
  - 50% @ 1000 MPa

**B-pillar Reinforced Panel**
HC600/980QP, (T=2.0 mm)

**Rear Floor Cross Member**
1180 GI

**Front Bumper**
1.4 mm

Black: Commercialized; Blue: Trial production; Red: under Developing
Advanced mechanical properties, excellent formability, competitive price, and lowest CO2 emission contribution in LCA, are the most irreplaceable characteristics of AHSS for the applications of auto lightweighting purposes.
2015 to 2025, huge drop in mild steel and major gain in AHSS deliveries; AHSS = Inexpensive way to reduce weight/lb; High strength, high elongation steels - the "new" material - not yet fully ready.
Thanks for your time