50 year Perspective of Automotive Engineering Body Materials and an Analysis of the Future

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Manager, Global Die Standards & Materials Applications
General Motors Manufacturing Engineering

Great Designs in Steel 2008
Steel Becomes the “Material of Choice” for Auto Bodies

- Original bodies made of wood & steel
- Quick to tool, easy to change
- Large number of skilled workers

- 1914 Dodge & Budd produce 5,000 all-steel bodies
- All-steel body was lighter, stronger, easier to make
- Most significant advantage was in painting

Benz Patent Motorwagen 1886 (Replica)

Dodge Brothers Touring Car 1917
“Every time the price of steel goes up, Detroit’s auto makers moan in anguish and intensify their search for replacements”
“Every time the price of steel goes up, Detroit’s auto makers moan in anguish and intensify their search for replacements”
Materials Causing the Biggest Stir in Body Technology

Plastics
- “been getting the big play … as successor to steel”

Aluminum Alloys
- “about as strong as steel, less than half the weight”
- “used …since birth of auto”
- “most plentiful metal on earth”

Magnesium Alloys
- “even lighter than aluminum, stronger for its weight than steel”
- “most easily machined and cast”
- “enough in the ocean… to provide 100,000,000 tons a year”
“The day of the passenger car made primarily of iron and steel is on the wane! Some sources predict that by 1960 a Cadillac will weigh less than a 1953 Chevrolet and a Chevy will probably weigh about as much as a motorcycle.”
Prediction 50+ Years Ago...

Steel

PAST

FUTURE

Mg

AI

Plastics
8

1953 – Chevrolet Introduces the Corvette w/ fiberglass body. Lightweight body improves all aspects of performance.

1997 – Audi introduces the first all aluminum volume production car. The Aluminum frames weigh up to less than 40% of steel frames of comparable design.

1950 - 2000+

Key Product Drivers & Resulting Vehicles

Clean Air Act
Highway Safety Act
Safety Focus
Oil Shock
Global Competition
Customer Personalization


Late 1970’s – Dodge releases Charger XL that applies higher strength steel and aluminum components that resulted in a 285kg reduction in vehicle mass.
Current Body and Closure Metallic Material
Content by Type for North America

Source: Ducker Worldwide
2007

- Mild Steel: 54.6%
- Advanced HSS: 9.5%
- Aluminum & Magnesium: 0.8%
- Conventional HSS: 12.7%
- Medium HSS: 15.8%
- Bake Hardenable Steel: 6.6%

850 Pounds

Mild Steel

Advanced HSS

Aluminum & Magnesium

Conventional HSS

Medium HSS

Bake Hardenable Steel

Source: Ducker Worldwide
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Bake Hardenable Steel
The Question is ...

Why do these materials continue to fall short of the prediction?
# Comparison of Materials by Performance

<table>
<thead>
<tr>
<th></th>
<th>Density</th>
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<th>Tensile Strength</th>
<th>Elongation</th>
<th>Corrosion Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mild Steel</strong></td>
<td></td>
<td></td>
<td>- - - - - - - -</td>
<td>BASELINE</td>
<td>- - - - - - - - - -</td>
</tr>
<tr>
<td><strong>Aluminum</strong></td>
<td>+</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>0 / +</td>
</tr>
<tr>
<td><strong>Magnesium</strong></td>
<td>+</td>
<td>- -</td>
<td>0</td>
<td>-</td>
<td>0 / -</td>
</tr>
<tr>
<td><strong>Polymers &amp; Composites</strong></td>
<td>+</td>
<td>0 / -</td>
<td>- / 0 / +</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

**KEY:**
- 0 = equal
- + = better
- - = worse
## Comparison of Materials by Manufacturability

<table>
<thead>
<tr>
<th>Material</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>• Formability</td>
<td>• Castability</td>
</tr>
<tr>
<td></td>
<td>• Weldability</td>
<td>• Lower formability than steel</td>
</tr>
<tr>
<td></td>
<td>• Infrastructure</td>
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</tr>
<tr>
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<td>Polymer/Composites</td>
<td>Advantages:</td>
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Comparison of Materials by Other Important Characteristics

<table>
<thead>
<tr>
<th>Material</th>
<th>Cost (Est. $/lb.)</th>
<th>Availability (Annual Metric Ton Production)</th>
<th>Environment (Primary Production Emissions reported by industry)</th>
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<tr>
<td>Mild Steel (Baseline)</td>
<td>$0.50</td>
<td>110 Million</td>
<td>• easy to recycle</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Emissions = 2.3 – 2.7 kg CO₂/kg</td>
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<td>Aluminum (Al)</td>
<td>$1.00</td>
<td>2.5 Million</td>
<td>• easy to recycle</td>
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<tr>
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<td>• Emissions = 13.9 – 15.5 kg CO₂/kg</td>
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<td>Magnesium (Mg)</td>
<td>$1.50</td>
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<tr>
<td></td>
<td></td>
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<td>• Emissions = 18.0 – 24.8 kg CO₂/kg</td>
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<tr>
<td>PMC</td>
<td>$1.20 - 6.50</td>
<td>Unknown</td>
<td>• difficult to recycle</td>
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Current Body and Closure Metallic Material
Content by Type for North America

- **Mild Steel**: 54.6%
- **Advanced HSS**: 12.7%
- **Medium HSS**: 15.8%
- **Bake Hardenable Steel**: 6.6%
- **Conventional HSS**: 9.5%
- **Aluminum & Magnesium**: 0.8%

**850 Pounds**

Source: Ducker Worldwide 2007
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<tr>
<td>HSS/AHSS</td>
<td>0</td>
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• Infrastructure  
• Painted Surface | • Castability |
| **Aluminum** | • Formability  
• Castability  
• Painted Surface | • Lower formability than steel  
• Weldability |
| **Magnesium** | • Castability  
| | • Formability  
• Elevated temperature stamping & hemming  
• Weldability |
| **Polymer/Composites** | • Low cost tooling  
• Shorter lead time | • Cycle Time  
• Infrastructure  
• Difficult to repair  
• Painted Surface |
# Comparison of Materials by Other Important Characteristics

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• Emissions = 13.9 – 15.5 kg CO₂/kg                                |
| Magnesium (Mg)      | $1.50             | 0.5 Million                                 | • easy to recycle  
• Emissions = 18.0 – 24.8 kg CO₂/kg                                |
| PMC                 | $1.20 - 6.50      | Unknown                                     | • difficult to recycle  
• Emissions = 2.5 – 23.0 kg CO₂/kg                                 |
| HSS/AHSS            | $0.55             | Included in Mild Steel                      | • easy to recycle  
• Emissions = 2.3 – 2.7 kg CO₂/kg                                 |
Steel Strategy

Elongation (%)

Tensile Strength (MPa)

Second Generation AHSS

Conventional HSS

First Generation AHSS
Steel Strategy - GAP

Elongation (%) vs. Tensile Strength (MPa)

Future Opportunity
Third Generation AHSS

L-IP
AUST. SS
TWIP

IF
IF-HS
Mild
ISO
BH
TRIP
CMn
HSLA
DP, CP
MART
What’s the same?

• Other than prediction of lightweight material usage and the elimination of steel (by some)
• Relative amongst materials:
  – Cost
  – Performance
  – Manufacturability
  – Availability
• Fuel Cost
• Strategy for material implementation
Engineering Strategy

Materials

Design

Manufacturing
Business Strategy

Manufacturability & Cost:
- material
- design
- manufacturing

Government Regulations
- Fuel Economy
- Crash Performance
- Emissions

& Customer Requirements
- Cost
- Quality/Styling
- Features
Steel Mass Reduction Opportunities

- **MILD STEELS**
- **CONV HSS**
- **AHSS**

With Steel Strategy & DOE Support

Without DOE Support

MASS COMPOUNDING 3rd GENERATION

FreedomCAR GOAL

Mass Reduction Opportunity


Time

Technology Decision
Global Market

North America
- Well developed market
- Consumer demand for large vehicles
- Primary challenges: U.S. CAFE and emissions regulations (particularly diesel); strict collision performance requirements

Latin America, Africa & Middle East
- Diverse market
- New market players
- Lead in alternative fuels, particularly ethanol
- Primary challenge: product cost
- Opportunity for more growth

Europe
- Well developed market
- Consumer demand for a balance of utility & efficiency
- Relatively high fuel prices
- Taxes on poor fuel economy & emissions
- Primary challenges: CO2 commitment and Euro 5 emissions; strict collision performance requirements

Asia Pacific
- Fast growing diverse market
- Infrastructure still developing
- Primary challenges are new fuel economy/emission regulations
China, with 13 vehicles per 1000 people, is where the U.S. was in 1913.

China’s population is currently 4 times the population of the U.S.
What materials will be used to meet these demands?
NORTH AMERICAN LIGHT VEHICLE METALLIC MATERIAL TRENDS

Body and Closure Metallic Material Content by Type

### 2007
- **Con. HSS**: 12.7%
- **Medium HSS**: 15.8%
- **Bake Hardenable**: 6.6%
- **Advanced HSS**: 9.5%
- **Aluminum & Magnesium**: 0.8%
- **Mild Steel**: 54.6%

**Total**: 850 Pounds

### 2015
- **Con. HSS**: 10.2%
- **Bake Hardenable**: 23.5%
- **Bake Hardenable and Medium HSS**: 2.5%
- **Advanced HSS**: 34.8%
- **Aluminum & Magnesium**: 2.5%
- **Mild Steel**: 29.0%

**Total**: 800 Pounds with an Equal Footprint to 2007

Source: Ducker Worldwide
## NORTH AMERICAN LIGHT VEHICLE METALLIC MATERIAL TRENDS

### North American Light Vehicle Material Content Per in Pounds

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild Steel</td>
<td>2,180</td>
<td>1,751</td>
<td>1,748</td>
<td>1,314</td>
<td>Down 866 lbs.</td>
</tr>
<tr>
<td>High Strength Steel</td>
<td>140</td>
<td>324</td>
<td>334</td>
<td>315</td>
<td>Up 175 lbs.</td>
</tr>
<tr>
<td>Advanced HSS</td>
<td>--</td>
<td>111</td>
<td>149</td>
<td>403</td>
<td>Up 403 lbs.</td>
</tr>
<tr>
<td>Other Steels</td>
<td>65</td>
<td>76</td>
<td>76</td>
<td>77</td>
<td>Up 12 lbs.</td>
</tr>
<tr>
<td>Iron</td>
<td>585</td>
<td>290</td>
<td>284</td>
<td>244</td>
<td>Down 341 lbs.</td>
</tr>
<tr>
<td>Aluminum</td>
<td>84</td>
<td>307</td>
<td>327</td>
<td>374</td>
<td>Up 290 lbs.</td>
</tr>
<tr>
<td>Magnesium</td>
<td>--</td>
<td>9</td>
<td>9</td>
<td>22</td>
<td>Up 22 lbs.</td>
</tr>
<tr>
<td>Other Metals</td>
<td>120</td>
<td>150</td>
<td>149</td>
<td>145</td>
<td>Up 25 lbs.</td>
</tr>
<tr>
<td>Plastic/Composites</td>
<td>180</td>
<td>335</td>
<td>340</td>
<td>364</td>
<td>Up 184 lbs.</td>
</tr>
<tr>
<td>Other Materials</td>
<td>546</td>
<td>629</td>
<td>634</td>
<td>650</td>
<td>Up 104 lbs.</td>
</tr>
<tr>
<td><strong>Total Pounds</strong></td>
<td><strong>3,900</strong></td>
<td><strong>3,982</strong></td>
<td><strong>4,050</strong></td>
<td><strong>3,908</strong></td>
<td><strong>Up 8 lbs.</strong></td>
</tr>
</tbody>
</table>

* Same vehicle mix and average footprint as 2007

Source: Ducker Worldwide
NORTH AMERICAN
LIGHT VEHICLE METALLIC MATERIAL TRENDS

Body and Closure Metallic Material Content by Type

North America

- Advanced HSS: 34.8%
- Conventional HSS: 10.2%
- Bake Hardenable and Medium HSS: 23.5%
- Mild Steel: 29.0%
- Aluminum & Magnesium: 2.5%
- & Others: 3.0%

Europe

- Mild Steel & BH: 25.0%
- Aluminum & Magnesium: 30.0%
- PHS, TWIP & Others: 12.0%
- Conventional HSS: 30.0%
- AHSS: 30.0%

2015
Why is this reasonable?

• No real changes in basic trends over past 50 years
• “Cash is King” – customer paying less than before & demanding more
• Infrastructure not ready
• Availability – Infrastructure of metal production
• Global Differences in Needs
What could ‘disrupt’ this prediction

- Fuel Cost & Availability
- Material Cost & Availability
- Economic Stability
- Government Regulations
- Technological Discoveries/Advances
Conclusions

• Always be a need/desire to push to lightweight materials for the auto industry
• Doesn’t mean no steel
• Current prediction is mainly some form of steel
  – Best value to customer (performance/cost)
• However, disruptive event(s) is as likely, or even more likely, than ever before