Surface Treatment of Aluminium Automotive Sheet: Mythology and Technology

Geoff Scamans, Peter Andrews, Colin Butler, Innoval Technology
George Thompson, Yanlong Ma and Xiarong Zhou, Manchester University
Andrew Hall, Alken
More people, more cars? 2 billion vehicles by 2020?

2 billion vehicles by 2020?

Historical & projected increases in global motor vehicle numbers

Car Ownership per 1,000 population of driving age 2007

Number of motor vehicles - Billions

Morgan Stanley

Aluminium Surface Science and Technology 6, Sorrento, 28th to 31st May 2012
2 billion Light Duty Vehicle (LDVs) by 2035?

Source: IEA
## Global Vehicle Statistics

<table>
<thead>
<tr>
<th></th>
<th>1930</th>
<th>1960</th>
<th>2000</th>
<th>2030 (forecast)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global population</td>
<td>2 billion</td>
<td>3 billion</td>
<td>6 billion</td>
<td>8.5 billion</td>
</tr>
<tr>
<td>Total number of vehicles on the road</td>
<td>36 million</td>
<td>136 million</td>
<td>767 million</td>
<td>1450 million</td>
</tr>
<tr>
<td>Total distance travelled (km)</td>
<td>2 trillion</td>
<td>13 trillion</td>
<td>23 trillion</td>
<td></td>
</tr>
<tr>
<td>Total fuel used (l)</td>
<td>280 billion</td>
<td>920 billion</td>
<td>2000 billion</td>
<td></td>
</tr>
<tr>
<td>Number of vehicles scrapped</td>
<td>5 million</td>
<td>36 million</td>
<td>116 million</td>
<td></td>
</tr>
</tbody>
</table>

From 2000 to 2030, 2,900 million vehicles will be produced and 2,200 million will be scrapped.
## Increase of Scrap Materials from ELVs

### Evolution of whole life vehicle scrap weight - MDCs vs DVCs - 1960 to 2030 - tonnes

![Graph showing the evolution of whole life vehicle scrap weight](image)

<table>
<thead>
<tr>
<th>Material</th>
<th>1960-2006</th>
<th></th>
<th>2007-2030</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>Aftermarket</td>
<td>ELV</td>
<td>Aftermarket</td>
<td>ELV</td>
</tr>
<tr>
<td>Iron</td>
<td>438.62</td>
<td>1,447.75</td>
<td>560.09</td>
<td>1,610.89</td>
</tr>
<tr>
<td>Non-ferrous</td>
<td>66.46</td>
<td>110.20</td>
<td>84.86</td>
<td>262.51</td>
</tr>
<tr>
<td>Plastics</td>
<td>22.15</td>
<td>123.06</td>
<td>28.29</td>
<td>279.86</td>
</tr>
<tr>
<td>Glass</td>
<td>8.86</td>
<td>54.06</td>
<td>11.32</td>
<td>73.98</td>
</tr>
<tr>
<td>Rubber</td>
<td>221.53</td>
<td>85.17</td>
<td>282.88</td>
<td>119.62</td>
</tr>
<tr>
<td>Others</td>
<td>15.73</td>
<td>91.61</td>
<td>200.84</td>
<td>139.23</td>
</tr>
<tr>
<td>Total</td>
<td>914.91</td>
<td>1,911.84</td>
<td>1,168.28</td>
<td>2,486.08</td>
</tr>
</tbody>
</table>

Pat Winfield, Sustainable Vehicle Engineering Centre, Oxford Brookes, December 2008

Aluminium Surface Science and Technology 6, Sorrento, 28th to 31st May 2012
New Passenger Cars: CO\textsubscript{2} Emissions by Vehicle Segment
New Passenger Cars: Vehicle Mass and CO₂ Emissions
Effect of curb weight on carbon emissions for petrol, diesel (2005) and hybrid vehicles (2010)
Average Light Vehicle Material Content in Pounds per Vehicle

<table>
<thead>
<tr>
<th>Material Category</th>
<th>2008</th>
<th>2010</th>
<th>2012</th>
<th>2015</th>
<th>2025</th>
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</thead>
<tbody>
<tr>
<td>Mild Flat Rolled Steel</td>
<td>999</td>
<td>976</td>
<td>861</td>
<td>650</td>
<td>408</td>
</tr>
<tr>
<td>FR BH &amp; HS Steel (HSLA)</td>
<td>489</td>
<td>496</td>
<td>513</td>
<td>516</td>
<td>240</td>
</tr>
<tr>
<td>Flat Rolled AHSS</td>
<td>124</td>
<td>156</td>
<td>194</td>
<td>251</td>
<td>375</td>
</tr>
<tr>
<td>All Other Steel (Long Products)</td>
<td>602</td>
<td>606</td>
<td>596</td>
<td>580</td>
<td>542</td>
</tr>
<tr>
<td>Flat Rolled Aluminum</td>
<td>29</td>
<td>31</td>
<td>34</td>
<td>67</td>
<td>156</td>
</tr>
<tr>
<td>Aluminum Extrusions</td>
<td>10</td>
<td>12</td>
<td>14</td>
<td>19</td>
<td>30</td>
</tr>
<tr>
<td>Structural Aluminum Castings</td>
<td>20</td>
<td>20</td>
<td>22</td>
<td>25</td>
<td>60</td>
</tr>
<tr>
<td>All Other Aluminum</td>
<td>266</td>
<td>267</td>
<td>273</td>
<td>289</td>
<td>304</td>
</tr>
<tr>
<td>Iron</td>
<td>307</td>
<td>305</td>
<td>295</td>
<td>290</td>
<td>270</td>
</tr>
<tr>
<td>Copper</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
</tr>
<tr>
<td>Other Metals</td>
<td>101</td>
<td>103</td>
<td>104</td>
<td>105</td>
<td>115</td>
</tr>
<tr>
<td>Polymers</td>
<td>340</td>
<td>345</td>
<td>350</td>
<td>366</td>
<td>400</td>
</tr>
<tr>
<td>Other Non Metallics</td>
<td>496</td>
<td>493</td>
<td>492</td>
<td>490</td>
<td>475</td>
</tr>
</tbody>
</table>

An argument can be made that the rise in AHSS is simply coming out of the decline of galvanized steel per vehicle Source: Ducker Worldwide
EU Aluminium Automotive Sheet Growth (kt)

Andrew Hall and Geoff Scamans: Aluminum for Auto Body Sheet, Light Metal Age December 2011
EU Aluminium Automotive Sheet Capacity (kt)

Growth in EU aluminium automotive sheet heat treatment and finishing capacity

- AMAG, Ranshofen
- Hydro, Grevenbroich
- Constellium, Neuf Brisach
- Aleris, Duffel
- Novelis, Sierre
- Novelis, Nachterstedt

Andrew Hall and Geoff Scamans: Aluminum for Auto Body Sheet, Light Metal Age December 2011

Aluminium Surface Science and Technology 6, Sorrento, 28th to 31st May 2012
Novelis Automotive Finishing Line in China

- Novelis to Build First Manufacturing Plant in China
- Newest Automotive Expansion Provides Unmatched Global Footprint
- SHANGHAI, April 10, 2012 /PRNewswire/ -- Novelis Inc., the world's leading producer of premium aluminum rolled products, today signed an agreement with the Changzhou National Hi-Tech District to build the company's first automotive sheet manufacturing facility in China. The agreement, which includes land use rights to more than 160 acres, was signed today at a formal ceremony in Changzhou City in the Jiangsu Province of China.

Novelis is the world's leading producer of rolled aluminum for the global automotive market and the leading provider of aluminum sheet to the rapidly expanding Chinese automobile industry. The wholly owned, $100-million plant will have a capacity of 120,000 metric tons per year and is expected to be commissioned for operation in late 2014.
## Relative Cost of Aluminium vs Steel Parts

### Steel Component = 1kg. Typically aluminium alloy would save 45% of Mass.

<table>
<thead>
<tr>
<th>Material</th>
<th>Minimum Gauge</th>
<th>Price/kg €uros</th>
<th>Mass of part kg</th>
<th>Price/part €uros</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild Steel (2) + Z100</td>
<td>No Limitation</td>
<td>0.400</td>
<td>1.000</td>
<td>0.400</td>
</tr>
<tr>
<td>HSS (DP600) + Z100</td>
<td>No Limitation</td>
<td>0.450</td>
<td>0.900</td>
<td>0.405</td>
</tr>
<tr>
<td>UHSS (Boron + AlSi)</td>
<td>No Limitation</td>
<td>0.600</td>
<td>0.800</td>
<td>0.480</td>
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<tr>
<td>AA5182</td>
<td>No Limitation</td>
<td>2.956</td>
<td>0.550</td>
<td>1.626</td>
</tr>
<tr>
<td>NG5754</td>
<td>No Limitation</td>
<td>2.956</td>
<td>0.550</td>
<td>1.626</td>
</tr>
<tr>
<td>AA6111</td>
<td>No Limitation</td>
<td>3.238</td>
<td>0.500</td>
<td>1.619</td>
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<tr>
<td>AA6016</td>
<td>No Limitation</td>
<td>3.167</td>
<td>0.550</td>
<td>1.742</td>
</tr>
<tr>
<td>Ac300</td>
<td>No Limitation</td>
<td>3.252</td>
<td>0.500</td>
<td>1.626</td>
</tr>
<tr>
<td>Extrusion AA 6014</td>
<td>Size related</td>
<td>6.000</td>
<td>0.600</td>
<td>3.600</td>
</tr>
<tr>
<td>HPDCastings</td>
<td>2</td>
<td>10.000</td>
<td>0.650</td>
<td>6.500</td>
</tr>
<tr>
<td>Sand Castings</td>
<td>3</td>
<td>12.000</td>
<td>0.700</td>
<td>8.400</td>
</tr>
<tr>
<td>Thermo plastic</td>
<td>some limitation</td>
<td>2.000</td>
<td>0.600</td>
<td>1.200</td>
</tr>
<tr>
<td>Composite</td>
<td>some limitation</td>
<td>3.000</td>
<td>0.700</td>
<td>2.100</td>
</tr>
<tr>
<td>HS Composite</td>
<td>some limitation</td>
<td>20.000</td>
<td>0.350</td>
<td>7.000</td>
</tr>
</tbody>
</table>

Aluminium Prices based upon LME of $2,050 US

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Mark White, Aluminium 2006, 21st International Aluminium Conference, Moscow 18/09/2006

Aluminium Surface Science and Technology 6, Sorrento, 28th to 31st May 2012
Aluminium LME Volatility and Targets

Mark White, Why does the car industry need light weight cost effective sustainable materials?
European Aluminium Congress, Dusseldorf, 2009

Strategic weight save only – Luxury/Sports
10 - 20KT per year maximum

Premium sector Sports/Saloons/SUVs
50 - 100KT per year maximum

Executive sector – all Models
100 - 250KT per year maximum in Eu

D & C/D Segment High Volume & Mixed Metal Cars
250KT - 500Kt per year plus in Eu

Mark White, Why does the car industry need light weight cost effective sustainable materials?
European Aluminium Congress, Dusseldorf, 2009
Relative price of UBC scrap compared to the average monthly LME aluminium price. On average it is 56% of the metal price. The orange line is the JLR price target for the aluminium price ($1400/tonne) for use in D and C/D sector cars.
Global Aluminium Beverage Can Collection Rates (2009)

* Includes unregistered collection
Automotive Sheet Recycling

Recycle
- Chemistry
- Scrap Value

Sheet Process
- Blending
- Chemistry Control
- Cold Rolling
- Annealing
- Finishing

Coil
- Slitting
- Cut-to-length
- Laser Blanking

Scrap
- Segregation
- Collection
- Handling
- Tier 2s

Old Scrap
- Transport scrap
- Building scrap
- Can scrap

Stamping
- Stamping
- Trim

Blank

Stamping

Recycle
Description:
Sheet unibody structure
SOP: 2003
Weight: painted BIW 295 kg
Volume (car/year): 30,000

Materials / parts:
Castings: 15 (5 %)
Extrusions: 22 (7 %)
Stampings: 273 (88 %)
Curb weight: -200 kg
249 to 299 g/km CO₂

Joining methods:
Adhesive bonding (114 m)
Self piercing rivets (3195)
Clinches: 110
MIG welds: 2 m
Blind rivets: 22

Special characteristics:
• 40 % lighter than steel
• 60 % stiffer than predecessor
Suitable for high volume production (> 100,000 units per year)
Jaguar XJ Body Design 2011
Jaguar XJ Body Structures Materials
### Jaguar XJ LWV Body Complete Overview

<table>
<thead>
<tr>
<th>Component type</th>
<th>Previous generation XJ</th>
<th>New XJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stampings</td>
<td>91%</td>
<td>88%</td>
</tr>
<tr>
<td>Castings</td>
<td>5%</td>
<td>6%</td>
</tr>
<tr>
<td>Profiles</td>
<td>4%</td>
<td>5%</td>
</tr>
<tr>
<td>Other</td>
<td>1%</td>
<td></td>
</tr>
</tbody>
</table>

AI sheet 5XXX
58% by mass

% by part count
BiW Weight Comparison with BMW Mini
## Current JLR Aluminium Applications

<table>
<thead>
<tr>
<th>Model</th>
<th>Body Structure</th>
<th>Fender</th>
<th>Bonnet</th>
<th>Roof</th>
<th>Doors</th>
<th>Tail Gate</th>
</tr>
</thead>
<tbody>
<tr>
<td>XK</td>
<td>alu</td>
<td>alu</td>
<td>alu</td>
<td>alu</td>
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<td>XF</td>
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<td>Discovery 4</td>
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<td>alu</td>
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<tr>
<td>Range Rover Sport</td>
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<td>Range Rover</td>
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<td></td>
<td>alu</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Mythology or Technology?

- Aluminium sheet requires surface texturing to enhance formability
- Aluminium closure sheet requires a stabilisation treatment
- Bonding of aluminium structural sheet requires aerospace quality pretreatment systems
- Aluminium automotive sheet is too expensive for the production of affordable volume production vehicles
Surface Texture

mill finished

EDT

Electrograined

Topochrome 1

Topochrome 2

Std EDT

theresa.warrender@novelis.com

Aluminium Surface Science and Technology 6, Sorrento, 28th to 31st May 2012
Deep Draw Square Pan Test - EDT and Mill with Production Applied Lubricant

Curves are 6th of 6 pressing

Ram Speed - 50mm.s⁻¹
Clamp Load - 400kN
Max. Displacement - 75mm

Load (kN)

Ram Displacement (mm)

Alub ZX EDT
Alub ZX Mill
Local Surface Damage due to EDT treatment
Local Surface Damage due to EDT treatment
Stabilisation or Passivation Treatment

- Developed at request of German OEMs for a surface resistance requirement for weldability
- Later work showed that the surface resistance measurement was unreliable and did not correlate with either weldability (MIG) or spot weldability
- Little or no benefit compared to a cleaned surface
- Still specified as a requirement by German OEMs
- Becoming a worldwide requirement
Adhesive Bonding of Aluminium

Influence of Adhesive Elastic Modulus on Vehicle Stiffness

<table>
<thead>
<tr>
<th>Adhesive E/E_XD4600</th>
<th>Relative Stiffness</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Bending</td>
</tr>
<tr>
<td>1.00</td>
<td>100%</td>
</tr>
<tr>
<td>0.67</td>
<td>99.5%</td>
</tr>
<tr>
<td>0.33</td>
<td>98.2%</td>
</tr>
<tr>
<td>0.10</td>
<td>94.2%</td>
</tr>
<tr>
<td>0.00</td>
<td>79.9%</td>
</tr>
</tbody>
</table>

dubravko.nardini@novelis.com
Australian Truck Specimens: 5 Years Exposure

- **Alcan AVT System**
  - ~300 days
  - 5 Years

- **Structural epoxy single part**
  - ~40 days
  - 5 Years

- **2-part epoxy**
  - 11 days
  - 2.6 Years

Legend:
- **S/H lifetimes**
- **Australia (no failures)**
- **Australia (failed)**
Neutral salt spray (NSS) test:
- 5% neutral salt spray fog at 43°C
- Joints exposed for 0 to 40 weeks
- Residual strength measured.
AA5754 Breaking load durability curves

![Graph showing breaking load durability curves for different treatments. The x-axis represents exposure time in weeks, ranging from 0 to 50. The y-axis represents breaking load in MPa, ranging from 0 to 30. The graph includes lines for CrPT, SiPT, AC, and TiPT treatments, indicating the durability performance over time.]
AA5754-O XD4600 / Etched only as bonded
AA5754-O XD4600 / Etched only aged 62 days
AA5754-O XD4600 / Etched only aged 109 days
AA5754-O XD4600 / Etched only aged 145 days
SEM and TEM of PT2 on AA5754
AA5754-O XD4600 / PT2 as bonded
AA5754-O XD4600 / PT2 aged 62 days
AA5754-O XD4600 / PT2 aged 62 days
AA5754-O XD4600 / PT2 aged 62 days
AA5754-O XD4600 / PT2 aged 109 days
AA5754-O XD4600 / PT2 aged 109 days

100 nm
AA5754-O XD4600 / PT2 aged 145 days
AA5754 Typical production sample from JLR
AA5754 Typical production sample from JLR
AA5754 Typical production sample from JLR
Summary

- Aluminium sheet can compete with steel for more affordable mass produced cars if the “cans to cars” principle is adopted
- The EDT surface treatment is an expensive processing extra with little or no benefit
- Stabilisation treatments are unnecessary as aluminium is protected by a thin stable oxide layer
- Cleaned only may still be an option for adhesive bonding but the jury is still out
- The volume of aluminium automotive sheet required could grow quickly to more than 1 million tonnes/year