Upcycling of Aluminium by Melt Conditioning Scrap

Geoff Scamans, Innoval Technology, Banbury, UK and BCAST and Zhongyun Fan, Director, BCAST (Brunel Centre for Advanced Solidification Technology), UK

Innoval Technology is an independent technology provider serving aluminium companies and end-users of aluminium. 27 engineers and materials specialists based in Banbury, Oxfordshire. BCAST is a Specialised Research Institute based at Brunel University, Uxbridge, UK
Fuel Consumption vs Vehicle Weight

- Gasoline Vehicles
- DI Diesel Vehicles

Stefan Pischinger, President and CEO, FEV Group, SAE Centennial 2005

Metal Bulletin’s 17th International Recycled Aluminium Conference, 24-25 November, Hotel Carlton, Bilbao, Spain
Complete database of vehicles on the market in 2006
VW 1-litre Concept Car (2002)

- The VW 1-litre car was so named because of its fuel consumption rating of just 1 litre per 100 km (equivalent to 282 mpg or 27g/100km).
- The car was produced under contract by the design company Stolfig.
- Carbon-fibre-reinforced outer skin tensioned over a magnesium spaceframe
- Car weight is 290 kg, Drag 0.16, 299cc 6.3kW diesel engine, range is 400 miles
- Limited production in 2010???

http://www.motorauthority.com/cars/volkswagen/vw-boss-confirms-1-liter-car-for-2010
Audi A2 1.2 TDi AIV (80g/km)

- First 4 door 3 litre car (2.99 litres/km)
- Axle mounting frame, control arms and spring struts, brake calipers on the front disc brakes and the brake drums at the rear are aluminium
- Lightweight forged aluminium wheels
- Weighs 825 kg (135 kg lighter than 1.4 TDi)
- The three cylinder aluminium 1.2 litre TDi engines is one of the lightest passenger-car diesel engines at 100 kg
- Produced at 20 cars/day (29,000 produced???)
- Never sold in UK and only 4 vehicles registered in UK
Upcycling of Aluminium by Recycling Scrap


- Body-in-White weight saving: ~54%
- Final finished vehicle weight saving: ~40%
- Vehicle weight: 909Kg
- Torsional Stiffness - Increased by 54%
- Bending Stiffness - Increased by 4%

Mondeo/Contour sized vehicle with mass reduced from 1508 to 909kg. 3L/100km vehicle maintaining all safety, durability, NVH and other functional attributes. Achieved through reduction in body structure, closure panel, seat, instrument panel trim etc., chassis, power train and fuel weight.

H J Cornille, J C Weishaar and C S Young, The P2000 Body Structure, SAE 982405
Passenger Vehicle Emissions

- **Petrol**
  - $y = 0.1328x + 3.4363$
  - $R^2 = 0.8408$

- **Diesel**
  - $y = 0.1001x + 12.455$
  - $R^2 = 0.9027$

- **Petrol Hybrid**
  - $y = 0.1045x - 18.387$
  - $R^2 = 0.9774$

With Audi 1.2 TDi and Ford P2000 AIV added.
Myths

- Aluminium is difficult to spot weld reliably and consistently
- Bonding of aluminium requires high modulus adhesives and aerospace quality pretreatment systems
- Aluminium sheet requires surface texturing to enhance formability
- Aluminium sheet requires a stabilisation treatment
- Aluminium intensive vehicles require purpose built finishing lines
- Aluminium automotive sheet is too expensive for the production of affordable volume production vehicles
- There is not enough aluminium
LME cash price for aluminium on 22 Apr 2008 was $3012.50/tonne
$1390.00/tonne on 11 Feb 2009 and $1646 on 29 Jun 2009
Aluminium production consumes 3% of the world’s electricity and 10% of world’s hydropower
Aluminium and CO₂ Emission Burden

Average emissions are 9.7kg CO₂e/kg Al
5.4kg from electricity + 4.3kg from mining, refining etc
Emissions can be much higher especially for old pot lines
and where electricity generation is coal based
(20.8kg CO₂e/kg Al just for electricity production)
Upcycling of Aluminium by Recycling Scrap

Direct and Indirect GHG Emissions from Primary Production 1990 to 2020 (estimated)


Metal Bulletin's 17th International Recycled Aluminium Conference, 24-25 November, Hotel Carlton, Bilbao, Spain
The Aluminium inventory – a mine of material & energy

- Since the 1880s, close to 800 million tonnes of aluminium have been produced.
- About three quarters of this metal is still in productive use.
- Recycling the metal currently stored in use would equal 17 years’ primary aluminium output.

1kg recycled Al saves 13kWh and 9.2 kg CO$_2$e

Note: this does not include aluminium in landfill sites
Actual and Predicted Return of Global Old Scrap

The amount of old scrap returned in 2003 (7 Mt) will double to (14 Mt) by 2020

Source: GARC, 24.01.05
Upcycling of Aluminium by Recycling Scrap

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

Stamping
- Stamping
- Trim

Old Scrap
- Transport scrap
- Building scrap
- Can scrap

Blank

Tier 2s

Stamping

Metal Bulletin’s 17th International Recycled Aluminium Conference, 24-25 November, Hotel Carlton, Bilbao, Spain
Energy Saving from Recycled Audi A2 1.2Tdi

Takashi Inaba: Automotive Engineering (ed. Cantor, Grant and Johnson 2008)
Melt Conditioning by Advanced Shear Technology (MCAST)
Upcycling of Aluminium by Recycling Scrap

TSB Technology Programme Spring 2006 Call: Advanced Materials: Materials for Extended First Use and Re-Use

Upcycling of Light Alloys by Reprocessing Scrap (ULARS)

Collaborative 3 year £1.6 million project started on 1st March 2007. Partners are Innoval, Meridian, Norton Aluminium, Zyomax and Brunel

Global supply of old aluminium scrap

Metal Bulletin’s 17th International Recycled Aluminium Conference, 24-25 November, Hotel Carlton, Bilbao, Spain
Upcycling of Aluminium by Recycling Scrap

MC-HPDC = MCAST+ HPDC

[Diagram showing HPDC Machine and MCAST process]
Melt shearing and Iron tolerance

Fe tolerance = 0.7wt%

Fe tolerance = 0.37wt%

LM24
(Al-9.3Si-3.2Cu-1.58Zn-0.3Mn)

LM25
(Al-10.3Si-0.3Cu-0.16Mn)
Microstructure of LM25 sand cast samples

Conventional sand cast

Melt conditioned sand cast
Upcycling of Aluminium by Recycling Scrap

Re-melting experiment

AZ91D, re-melted at 650°C

With shearing

Without shearing
Images of sections through filter residue from an LM24 alloy (Al-9.4Si-2.3Cu-1Zn-0.8Fe-0.5Mg-0.2Mn) showing the effect of high shear melt conditioning on the oxide film morphology and the intermetallic particle size.
MCAST: Nucleation Control

SEM image of LM24 filtrate

Sheared at 640°C
Melt Conditioned Twin Roll Casting Process (MC-TRC)

Production of aluminium alloy sheet made using a high proportion of wrought product scrap with properties to match AA5754 and AA6111 for lightweight automotive BIW construction.
Comparison of grain structure and segregation in grain refined AA5754 (0.4 wt% Fe) twin roll cast with and without melt conditioning. (Longitudinal and transverse sections across the strip)
Melt Conditioned Twin Roll Casting of Magnesium

AZ31 strip, 4mm thickness, as-cast

TRC

MC-TRC
Recycling: Good and Bad Recovery

Building – up to 98%
The sector used 13 million tonnes in 2007

Beverage cans – 66%
The sector used 4.5 million tonnes in 2007

Transport – up to 95%
The sector used 14.5 million tonnes in 2007
Can Recovery and Recycling in the UK

In UK alone 45kt of aluminium cans are lost (landfilled??) every year (90kt sold: 6.7 billion cans)
Total European BIW structure market for aluminium is 34kt
UK wastes 3 billion, Spain 1.9 billion and Italy 1 billion cans/year (2002 figures)
30kt/year are recycled into canstock (15kt/year castings or export??)
At Latchford each kg of recycled Al carries the low environmental burden of 0.68kg CO$_2$e/kg from decoating, melting and casting
Chemical Composition of Cans

<table>
<thead>
<tr>
<th></th>
<th>Fe</th>
<th>Si</th>
<th>Mg</th>
<th>Mn</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA3104 Can Body</td>
<td>0.4</td>
<td>0.2</td>
<td>1.2</td>
<td>0.9</td>
<td>0.2</td>
</tr>
<tr>
<td>AA5182 Can End &amp; Tab</td>
<td>0.2</td>
<td>0.1</td>
<td>4.7</td>
<td>0.3</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>Remelted UBC's</td>
<td>0.35</td>
<td>0.17</td>
<td>1.6</td>
<td>0.7</td>
<td>0.15</td>
</tr>
<tr>
<td>AA5754 Structural alloy</td>
<td>0.2</td>
<td>0.1</td>
<td>3.0</td>
<td>0.3</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>AA6016 skin alloy</td>
<td>0.2</td>
<td>1.2</td>
<td>0.5</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>AA6111 skin alloy</td>
<td>0.2</td>
<td>0.7</td>
<td>0.7</td>
<td>0.3</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Recycled cans that are presently lost to landfill are a potential low cost source of automotive sheet. Aluminium loose can scrap is £550 ($923) /tonne (Nov 2009)
Cans for Cars

45 kt of recovered cans would provide aluminium sheet for 140k Ford Prodigy AIVs
UK requirement is for 250k/year of <100g/km vehicles by 2012

In 2001 the recovery rate of UBCs in Japan was 83% and the can to can rate was 68%
In North America can recovery rates are similar to the UK except in states which use a
deposit system but 95% of recovered UBCs go back into can sheet
In the UK 50% are recovered and 33% are can to can recycled
Can to can recycling in Europe appears to be limited by decoater capacity
Adoption of aluminium sheet for the mass production of low CO₂ Aluminium Intensive Vehicles is limited by the present price of sheet. The aluminium automotive sheet market should be considered as similar to the can sheet market in order to compete effectively with steel.

Aluminium becomes a green metal once it is recycled and the focus of the industry should be on recycling rather than increased primary production (plus non-consumable anodes and carbon capture). Melt conditioning by advanced shear technology is a key enabling technology for recycling and impurity tolerance.

There is significant potential to increase sheet tonnage in the automotive market sector by increased recovery and high level recycling of old scrap and specifically by the increased recovery of cans.

The only low emission aluminium intensive vehicle in modest volume production (Audi A2 1.2 TDi) is no longer in production. The 1998 PNG 2000 Ford Contour with a more appropriate build technology remains a concept only. AIVs from recycled aluminium could be made in sufficient volume to have a dramatic impact on CO₂ emissions.