Light-weighting with magnesium: A viable option for Industry?

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CSIRO Future Manufacturing

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Magontec
Australia - a light-weight leader?

1. Can compete – by being clever and innovative

2. Has expertise in light metals technologies – The CSIRO, AutoCRC, CASTCRC, the universities – built up over more than 30 years

3. Has substantial mineral resources, and strong linkages with magnesium suppliers (e.g. Magontec)

4. Has innovative manufacturing technologies - T-Mag / Carbon Fibre

*We have a role to play in manufacturing for sustainability*
Magnesium

A role in achieving sustainability in vehicle applications

BMW composite engine block in magnesium and aluminium alloys
Vehicle weight & CO$_2$ emissions

- Vehicle weight and CO$_2$ emissions are inextricably linked

- Plot shows relationship between kerb weight & CO$_2$ emissions for European vehicles

- Best fit shows that a 100kg vehicle weight reduction reduces CO$_2$ emissions by 9.7g CO$_2$/km

Vehicle emissions plotted against vehicle weight for Europe in 2006
source: VDA (German Association of the Automotive Industry)
Financial incentives to reduce vehicle CO\textsubscript{2} emissions – avoid future $ penalties!

- Current EU fleet average CO\textsubscript{2} emissions: 140.3 gCO\textsubscript{2}/km
- 2015 target: 130 gCO\textsubscript{2}/km
- 2020 target: 95 gCO\textsubscript{2}/km
- Penalty of €95 per gCO\textsubscript{2}/km in excess of the limit
- If current 140.3 gCO\textsubscript{2}/km maintained by 2020 then penalty = €4300/vehicle

(T&E EU Federation of Transport & Environment 2010; published 09.2011)
Magnesium & vehicle weight reduction
- the lightest structural metal

Current Mg applications

*Engine blocks and bed plates*

*Transmission housings • Intake manifolds*

*Transfer case • Clutch housing • Engine cradle*

*Oil pans • Engine cover • Support brackets & housings*

*Timing chain case • Power steering pump bracket*

These parts are almost exclusively *high pressure die castings*. As such, they do not represent premium structural applications. Even in advanced vehicles:

> The opportunity for weight reduction is not being maximised
Currently the use of magnesium is determined by the application

- High pressure die cast magnesium alloy used for the engine cradle
- The suspension arm on the same vehicle is an aluminium component

Why not a magnesium alloy suspension arm in this car?

Suspension arm in permanent-mould cast and/or forged aluminium alloy = ‘premium application’

Sub-frame in high pressure die cast AE44 magnesium alloy

GM Corvette Z06
Magnesium

Economic manufacturing for automotive applications
⇔ casting processes

T-Mag cast engine mount brackets
Few premium “high-duty” cast Mg components

Challenges with production and cost

**High pressure die casting:**
Castings not heat-treatable, lesser mechanical properties and lower reliability; no hollow castings, capital intensive – needs high production volumes

**Sand casting**
Melt oxidation, low poured yield, casting reliability, critical process control, investment for volume production

**Gravity die casting:**
Metal oxidation, poor temperature control, low poured yield

**Low Pressure Die Casting:**
Difficult cover gas application, oxide control issues in metal delivery

Magnesium alloys oxidise readily...

... these oxide particles give poor casting properties...

...or even black castings!
T-Mag *economically* eliminates problems with volume production of premium magnesium castings

- Suited to high integrity applications – e.g. suspension, wheels & under-body components
- Designed after experience with gravity die casting of magnesium
- Considers melt oxidation control, ease of pouring, metal temperature control, high casting yield, and overall simplicity

Suspension knuckle production Mk2 machine
Movie of kart wheel production Mk1 machine
T-Mag development projects

- Electric Vehicle
- Wheel
- Suspension Parts
- Fuel Cell
- Engine Mount
- Engine
- GO Kart Racing Wheel
Magnesium case study
T-Mag engine mount bracket development*

*an AutoCRC funded project

FEA Analysis Result
Case no. 29: ‘Maximum Positive Rotations/MT Forces’
[Fx = -14.7kN  Fy = -4.2 kN  Fz = -7.6 kN]
T-Mag cast magnesium engine mount bracket

Baseline:
A 2\textsuperscript{nd}-generation high pressure die cast aluminium alloy component, weight 731g
- Satisfy geometric constraints of engine & chassis, plus required assembly clearances
- 29 specified loading cases to be met
- Minimum 1st mode natural resonance frequency of 1000 Hz

T-Mag component performance objectives:
- Weight reduction
- Improve damping & resonance for NVH by
  - design for improved stiffness
  - exploit magnesium’s intrinsically superior damping behaviour
HPDC vs. T-Mag bracket designs

The new design accommodated both the material and the process

- “Minimum necessary change” approach adopted
- General wall thickness increased 1.45 times
- Lowered transverse rib
- Fillet radii increased

HPDC aluminium 730 g

T-Mag Mg Design 562 g
Comparison of Al & T-Mag brackets

<table>
<thead>
<tr>
<th></th>
<th>T-Mag</th>
<th>HPDC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(SC1 Magnesium alloy)</td>
<td>(Aluminium Alloy 313)</td>
</tr>
<tr>
<td>Typical weight (g)</td>
<td>562 g</td>
<td>731 g</td>
</tr>
<tr>
<td>Weight as percentage of Al (%)</td>
<td>76.9 %</td>
<td>100 %</td>
</tr>
<tr>
<td>Typical fracture load (kN)</td>
<td>44 - 50 kN</td>
<td>44 - 48 kN</td>
</tr>
<tr>
<td>Deflection at fracture (mm)</td>
<td>8 – 10 mm</td>
<td>7.5 – 8.5 mm</td>
</tr>
<tr>
<td>1\textsuperscript{st} mode resonance frequency</td>
<td>1093 Hz</td>
<td>898 Hz</td>
</tr>
</tbody>
</table>

The T-Mag parts

- were 23% lighter
- had similar strength
- had a higher (design) resonance frequency
- will have better vibration damping characteristics.
Magnesium

Material Supply and Sustainability

Magontec Qinghai cast house under construction
Smelter due for completion in 2013
Whole of life-cycle aspects
Magnesium vs. other common materials

A life cycle analysis* of cast engine blocks determined the “GHG emission kg CO\textsubscript{2}-equivalent/engine block” for a vehicle life of 200,000 km.

Best sustainability resulted when using the newer technologies in Mg metal production and Mg alloying and casting practice

<table>
<thead>
<tr>
<th>Material</th>
<th>kg GHG equiv/component lifetime*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mg alloy</td>
<td>1900</td>
</tr>
<tr>
<td>Al alloy</td>
<td>2500</td>
</tr>
<tr>
<td>Fe (iron)</td>
<td>5300</td>
</tr>
</tbody>
</table>

Primary Metal Production: Mg vs. Al

Most magnesium is currently produced in China
- “Green credentials” challenged by environmentally unfriendly Pidgeon magnesium production technology
- Older style Pidgeon plants emit up to 40t CO$_2$/ton magnesium. For modern plants this figure is around 25t
- Average emissions for aluminium worldwide ~12t CO$_2$/ton aluminium

*Pidgeon magnesium plant belong to the past – we need to use new technology*

New Developments
- New electrolytic facilities greatly reduce CO$_2$ emissions to below Al on volume basis
Comparative Chinese GHG/CO₂ emissions

Average 26.2kg CO₂ eq/kg Mg

Pidgeon Process*

<table>
<thead>
<tr>
<th></th>
<th>Dolomite Mi</th>
<th>Ferrosilicone</th>
<th>Fluorite</th>
<th>Calcination</th>
<th>Briquetting</th>
<th>Reduction</th>
<th>Refining</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Producer gas</td>
<td>0.3</td>
<td>9.4</td>
<td>0.1</td>
<td>9.5</td>
<td>0.6</td>
<td>5.6</td>
<td>1.1</td>
<td>26.6</td>
</tr>
<tr>
<td>Coke Oven Gas</td>
<td>0.3</td>
<td>9.4</td>
<td>0.1</td>
<td>7.9</td>
<td>0.6</td>
<td>3.5</td>
<td>0.5</td>
<td>22.3</td>
</tr>
<tr>
<td>Semi Coke Oven Gas</td>
<td>0.3</td>
<td>9.4</td>
<td>0.1</td>
<td>10.8</td>
<td>0.6</td>
<td>5.8</td>
<td>0.7</td>
<td>27.7</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>0.3</td>
<td>9.4</td>
<td>0.1</td>
<td>9.5</td>
<td>0.6</td>
<td>4.3</td>
<td>0.8</td>
<td>25.0</td>
</tr>
</tbody>
</table>

Average 26.2kg CO₂ eq/kg Mg

Qinghai Electrolytic#

<table>
<thead>
<tr>
<th></th>
<th>Brine Purification</th>
<th>Evaporation</th>
<th>Drying</th>
<th>Reduction</th>
<th>Refining &amp; Casting</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Series1</td>
<td>0.2</td>
<td>1.94</td>
<td>3.73</td>
<td>0.10</td>
<td>0.50</td>
<td>6.47</td>
</tr>
</tbody>
</table>

6.5 kg CO₂ eq/kg Mg

*Simone Ehrenberger. German Aerospace Centre, Institute of Vehicle Concepts. IMA LCA Study. May 2012

# Hatch – Qinghai Integrated Magnesium Project Overview. July 2012
Mg production CO$_2$ emissions by region

The future of Mg production: < 10kg CO$_2$/kg Mg
Magnesium Recycling

Some specialist suppliers of Mg melting & refining equipment:

- Metamag Inc., Strathroy, CANADA
  www.metamag.com
- StrikoWestofen GmbH, Wiehl-Bomig, GERMANY
  www.strikowestofen.com
- Rauch Ing. Rauch-Fertigungstechnik GmbH, Gmunden, AUSTRIA
  www.rauch-ft.com

Some significant Mg recycling facilities:

- Advanced Magnesium Alloys Corporation (AMACOR) Indiana, U.S.A. Mg scrap recycling and ingot supply to 50,000 t/annum  www.amacor.us
- Aleris Recycling (German Works) GmbH, Grevenbroich, GERMANY
  www.aleris.com  Mg recycling to 10,000 t/annum
- MAGONTEC GmbH, Bottrop, GERMANY & Xian CHINA
  www.magontec.com
- RIMA Industrial S/A, Minas Gerais  BRAZIL
  www.rima.com.br

*Equipment & infrastructure for magnesium recycling are now well established*
Light weighting with magnesium
Cost considerations

T-Mag engine mount bracket
Destructive pull testing
T-Mag process economics can be compared to low pressure die cast aluminium production

Processes generally comparable in terms of:
- Size, complexity & engineering of the machinery and tooling;
- General operation and productivity
- Workforce skills, support equipment and maintenance

Significant points of difference are:
- Costs - magnesium vs. aluminium alloys
- Centralised melting and liquid transfer normal with Al, ingot pre-heater/feeder at T-Mag machine
- The requirement for cover gas with T-Mag.
Magnesium – material costs

- Mg alloys typically cost ~10% more than aluminium on a per component basis, without considering future emissions-based penalties.
- Market fluctuations have seen Mg cheaper than Al several times in recent years.
- With CO$_2$ penalties included, Mg is more than 25% cheaper than Al.
- Similar advantages may apply over steel but comparison is more complex: not a comparison of die cast components.
- High costs of carbon fibre materials outweigh any savings from penalty reductions.

[Mandated targets for recyclability in the EU are likely to severely limit the automotive application of carbon fibre components due to the limited recyclability of this material]
Melt cover gases and Mg casting
- environmental and dollar costs

- Cover gases are needed to stop magnesium melts from burning
- Older style SF$_6$ active cover gases are no longer recommended because of an extremely high GHG equivalence; HFC refrigerant-type gases are now preferred
- An HFC-type cover gas mix used to make a typical 5 kg T-Mag casting will consume not more than 1.4 grams of active cover gas per part:
  - at a cost of ~$0.34
  - with an emission of 2.2 kg/casting of green house gas (GHG) equivalent
  - which equates to approximately 16km worth of CO$_2$ emissions when operating a typical vehicle.

An acceptable sustainability performance?
Light weighting with magnesium

Conclusions

Porsche Panamera
Curb weight (DIN):
V8S (2WD): 1770 kg
V8T (4WD): 1970 kg
Conclusions

• Weight reduction is a key to improving vehicle sustainability, as measured by CO$_2$ emissions

• Component weight savings of 20+ % have been demonstrated with T-Mag magnesium castings

• New magnesium smelting technologies are reducing CO$_2$ emissions to levels below that for aluminium production

• Recycling of magnesium materials back into high quality alloy has become an economic and commercial reality

• In general, the ‘newest and best’ technologies always should be used to maximise sustainability

Magnesium is a sustainable option and a key to successful light-weighting
Further information
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